Report

Task 4: Problem and Solution Identification and Prioritization for Four Mile Run, Alexandria, Virginia

Prepared for

City of Alexandria
Transportation and Engineering Services

February 2016

CH2MHILL®

Baker

Executive Summary

The City of Alexandria, Virginia (the City) has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed. The watersheds include Hooffs Run, Four Mile Run, Holmes Run, Cameron Run, Taylor Run, Strawberry Run, Potomac River, and Backlick Run.

This report focuses on problem and solution identification (Task 4) for capacity issues in Four Mile Run. It summarizes the problem identification steps, solution development, solution scoring, and alternatives analysis. This task has resulted in three watershed-wide alternatives aimed at resolving capacity-related problems in the Four Mile Run watershed. Additionally, Task 4 has provided the City with a decision-making process for evaluating the benefits of potential stormwater management (SWM) projects.

The objectives of this phase of the study were to: (1) identify and prioritize capacity problems based on modeling results from Task 2 of this project, and (2) develop and prioritize solutions to address those problems.

The first objective of the study, identifying and prioritizing problems, was accomplished in two steps. The first step included evaluation of each stormwater junction in the drainage network using a scoring system to identify problems based on several criteria, including: the severity of flooding, proximity to critical infrastructure and roadways, city staff and public identification of problems, and opportunity for overland relief. In the next step, high scoring junctions (that is, higher priority problems) were grouped together to form high-priority problem areas. In total, 23 high-priority problem areas were identified in the Four Mile Run watershed. Flooding at locations outside of the high-priority problem areas were either flooding at isolated structures, or did not score high based on the problem area scoring criteria. These flooding problems were not addressed in this project.

The second objective involved developing and prioritizing solutions to address capacity limitations within the 23 high-priority problem areas. Several strategies were examined to accomplish this objective, including improving conveyance by increasing hydraulic capacity, reducing capacity limitations by adding distributed storage to the system, and reducing stormwater inflows by implementing green infrastructure(GI). Each of these strategies required a different modeling approach. Conveyance improvements were modeled by increasing pipe diameter in key locations within the problem area, storage was added at storage nodes based on a preliminary-siting exercise, and GI was modeled as a reduction in impervious area at three different implementation levels (high, medium, and low). A single model run was set up for each strategy including solutions for all 23 high-priority problem areas and the results were compiled for the alternative and prioritization evaluation. Solutions were evaluated based on several criteria, including drainage improvement and flood reduction, environmental compliance, sustainability and social benefits, asset management and maintenance implications, constructability, and public acceptance. Planning-level capital costs were developed for each solution to facilitate a benefit/cost analysis and prioritization process.

The results of the solution identification and prioritization analysis show the following:

- Solution technology performance:
  - GI generally has the greatest overall benefit as defined by the solution evaluation scoring system described in this report.
  - Conveyance solutions and storage solutions generally provide the greatest flood reduction of the technologies and approaches analyzed in Four Mile Run.
  - Combination of conveyance or storage projects and GI generally provides the greatest benefit and flood reduction.

- Costs:
  - Low level of GI implementation generally has the greatest benefit/cost score but did not usually meet minimum threshold for flood reduction.
  - Conveyance and storage projects generally provide the most economical stormwater volume reduction in terms of dollars per gallon of flood reduction within a high-priority problem area.
  - Combination of conveyance and GI generally provides the greatest overall benefit/cost score.

The following three watershed-wide alternatives were developed:

- Alternative 1: Most cost-effective solution for each problem area (lowest $/gallon of flood reduction)
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of best projects to address the worst problem areas to the extent practicable

The results for each alternative reflects the objective of that particular alternative. A summary of the results is provided in Table ES-1.

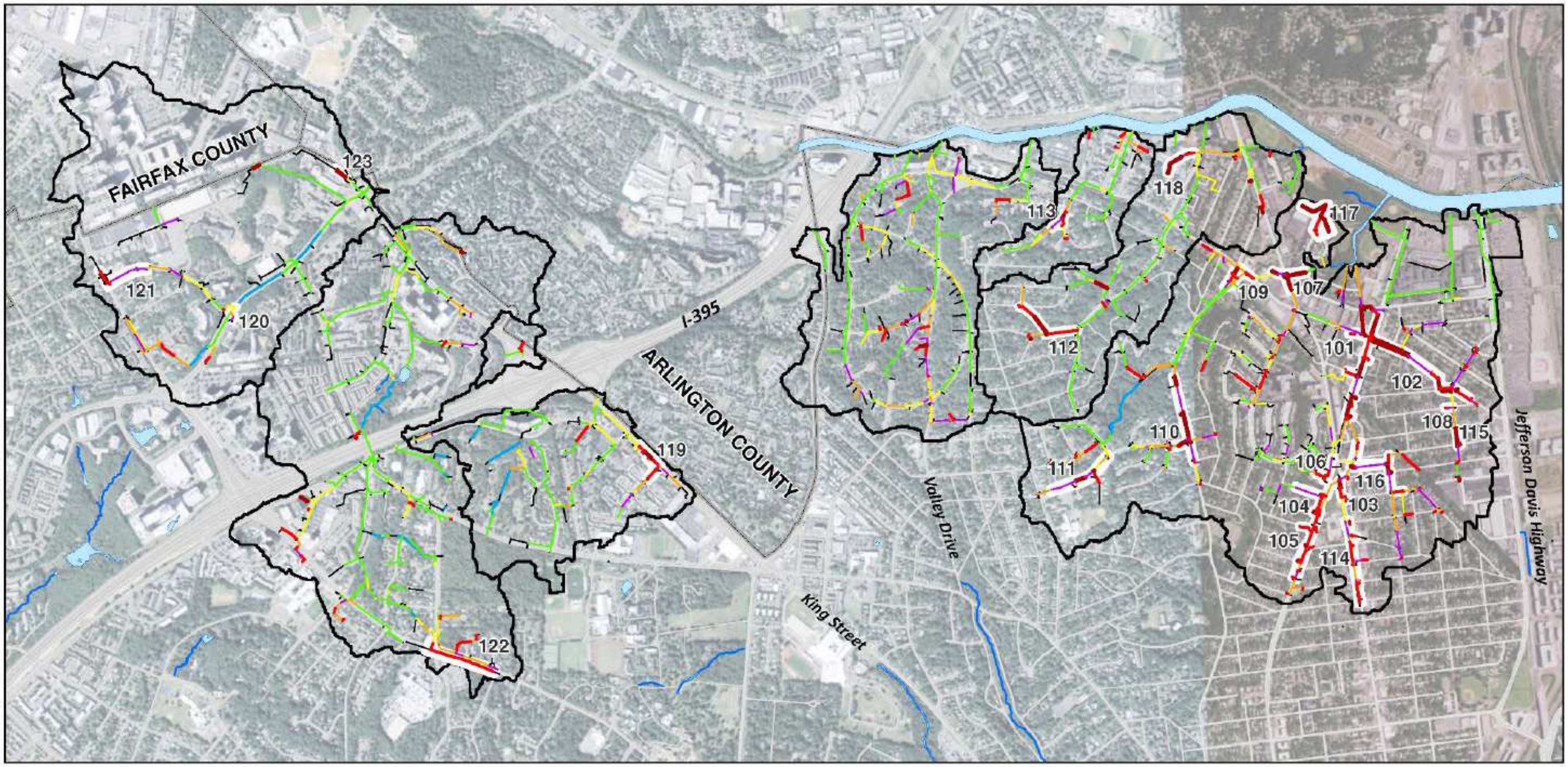
TABLE ES-1
Watershed-wide Alternatives Scoring and Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

	Alternative 1 - Best Cost Efficiency	**Alternative 2 - Best Benefit/Cost Ratio**	**Alternative 3 – Highest-priority Problems**
Total Capital Cost ($ Millions)	$21.7	$19.8	$24.5
Total Benefit Score	754	954	939
Overall Benefit/Cost	34.7	48.2	38.4
Total Flood Reduction (MG)	10.84	7.90	11.53
Cost of Flood Reduction ($/gallon)	$2.00	$2.50	$2.12

Note:
Several problem areas experience a small increase in flooding in all three alternatives. The flood volume increase in these problem areas is reflected in the total flood reduction numbers.

The watershed-wide results show that all three alternatives provide potential advantages when compared to the others. Alternative 1 has the best cost efficiency in terms of cost of flood reduction, but lowest overall benefit, Alternative 2 provides the greatest cost/benefit, but lowest flood reduction, and Alternative 3 provides the greatest total benefit score, but has the highest capital cost. Since the objective of this study is to provide flood reduction and relieve capacity limitations in the identified problem areas, Alternative 3 is the recommended alternative due to the amount of flood reduction achieved relative to cost and overall benefit. Though this alternative does not have the highest benefit or benefit/cost score of the three watershed-wide alternatives, Alternative 3 provides similar cost efficiency to Alternative 1, but with a higher overall benefit score. Model results for the existing conditions and the Alternative 3 watershed-wide alternative are presented in Figures ES-1 and ES-2.

FIGURE ES-1
Existing Conditions Model Results and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



Legend

Model Results
- Sufficient Capacity
- Surcharged
- Insufficient Freeboard

Flooded Volume (cu. ft.)
- 0.1 - 1,000
- 1,000 - 10,000
- 10,000 - 206,000
- Not Analyzed (Private, disconnected, upstream of runoff input)

- Modeled Streams
- City of Alexandria Streams
- Water Bodies
- Subwatersheds

Existing Conditions Model Results and High Priority Problem Areas

Task 4 Problem and Solution Identification and Prioritization for Four Mile Run, City of Alexandria, Virginia

0 1,000 2,000 4,000
Feet

N

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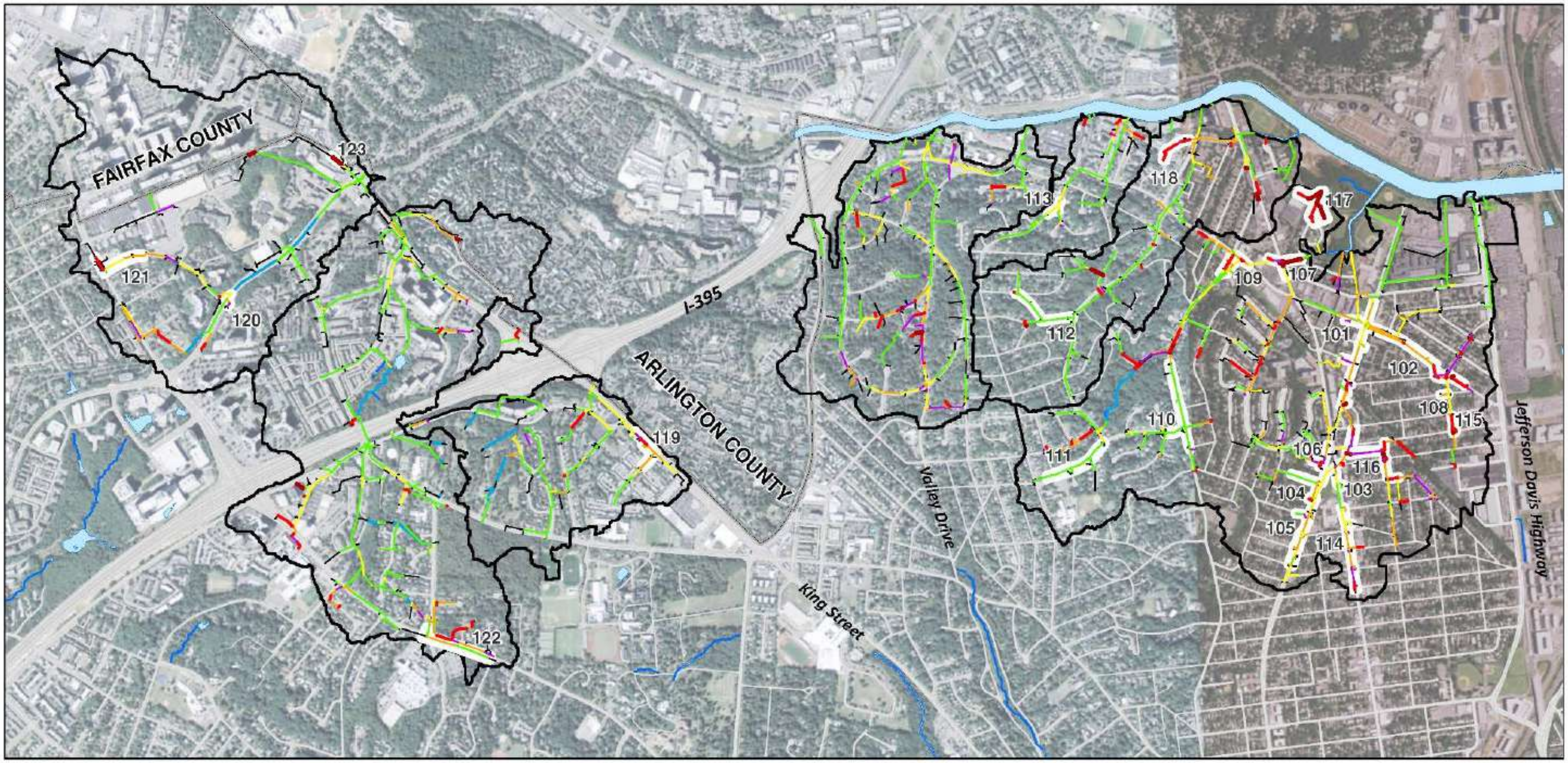
FIGURE ES-2
Alternative 3: Highest-priority Problems and High-priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



Legend

Model Results
- Sufficient Capacity
- Surcharged
- Insufficient Freeboard

Flooded Volume (cu. ft.)
- 0.1 - 1,000
- 1,000 - 10,000
- 10,000 - 142,000
- Not Analyzed (Private, disconnected, upstream of runoff input)

- Modeled Streams
- City of Alexandria Streams
- Water Bodies
- Subwatersheds

Watershed Wide Alternative 3: Overall Benefit Score Model Results and High Priority Problem Areas
Task 4 Problem and Solution Identification and Prioritization for Four Mile Run, City of Alexandria, Virginia

0 1,000 2,000 4,000
Feet

N

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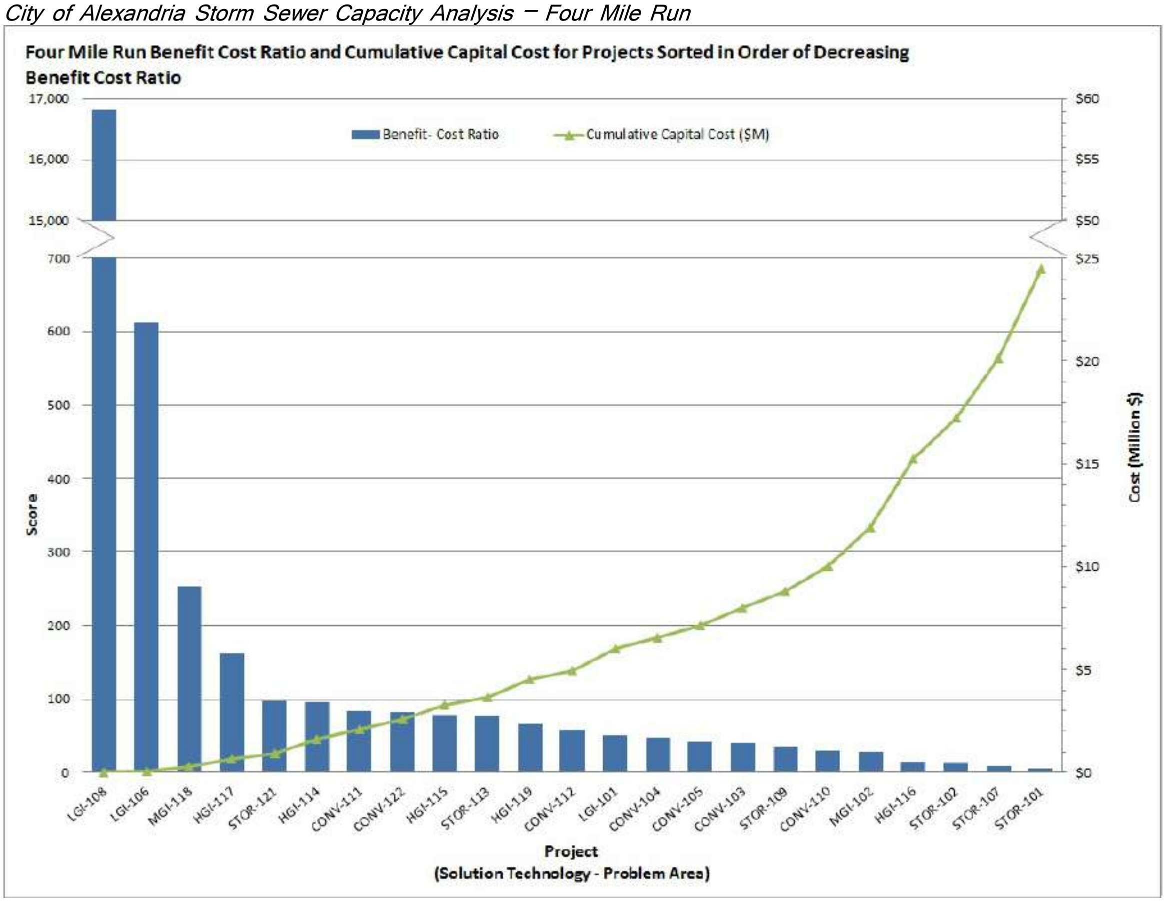
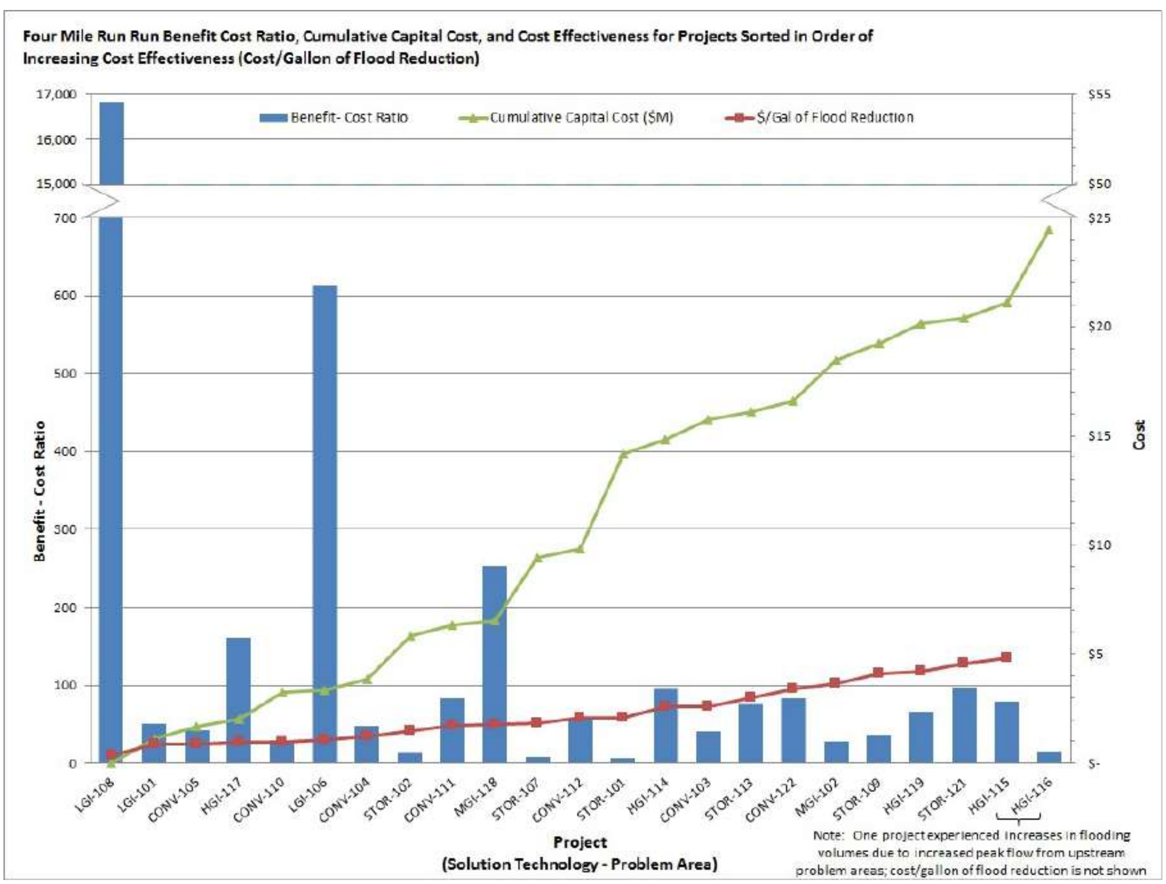
When developing a capital improvement plan, the benefit/cost or cost efficiency ($/gallon of flood reduction) are typically used to guide the order in which projects are implemented. Prioritization results for Alternative 3 are presented in Figure ES-3. The top chart shows the total benefit score and the cumulative capital cost of the alternative. The solutions are provided in order of decreasing benefit/cost ratio; solutions with the greatest benefit/cost are presented on the left and solutions with the lowest benefit/cost are presented on the right. The bottom chart shows the benefit/cost ratio for each solution in the watershed-wide alternative in order of increasing cost/gallon of flood reduction. Both charts show the cumulative capital cost plotted on the secondary axis. The solutions on both charts are named by the technology: conveyance (CONV), storage (STOR), low GI (LGI), medium GI (MGI), or high GI (HGI), and the problem area number.

Note that the model does not include analysis on private property, but applies assumed runoff loads as inputs to the public conveyance system. The City chose not to include existing private or public stormwater management facilities upstream of the modeled collection system because of the limited available information on these facilities and a concern that the facilities may not be performing as designed. When the City moves forward into detailed evaluation and design of selected projects, it will be important to fully evaluate and account for the benefits of any existing stormwater management facilities.

The hydraulic modeling results and costs presented in this report should be reviewed with the understanding that several assumptions were made to fill data gaps in the hydraulic model, and proposed solutions and costs were developed on a planning level.

FIGURE ES-3
Alternative 3: Highest-priority Problems Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run





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Acronyms and Abbreviations

bgs	below ground surface
cfs	cubic feet per second
City	City of Alexandria, Virginia
ft^2	square feet
ft^3	cubic feet
GI	green infrastructure
HGI	high green infrastructure
HGL	hydraulic grade line
hrs	hours
ID	identification
IDF	intensity-duration-frequency
LF	linear feet
LGI	low green infrastructure
MG	million gallons
MGI	medium green infrastructure
ROW	right-of-way
SWM	stormwater management
TM	technical memorandum

SECTION 1

Project Introduction

The City of Alexandria, Virginia (the City) has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed. This report focuses on problem and solution identification (Task 4) for capacity issues in Four Mile Run.

1.1 Background

The project consists of four major subtasks related to the model development and modeling. These four tasks and related technical memorandums (TMs) are described as follows:

- Task 1 – Review and propose revisions to the City's stormwater design criteria.
  - *Updated Precipitation Frequency Results and Synthesis of New IDF Curves for the City of Alexandria, Virginia (CH2M HILL, 2009a)*
  - *Sea Level Rise Potential for the City of Alexandria, Virginia (CH2M HILL, 2009b)*
  - *Rainfall Frequency and Global Change Model Options for the City of Alexandria (CH2M HILL, 2011)*
- Task 2 – Analyze the City's stormwater collection system capacity.
  - *Inlet Capacity Analysis for City of Alexandria Storm Sewer Capacity Analysis (CH2M HILL, 2012)*
  - *Stormwater Capacity Analysis for Four Mile Run Watershed, City of Alexandria, Virginia (CH2M HILL & Baker, 2016)*
- Task 3 – Survey collection system facilities on pipes 24 inches and larger to fill data gaps.[1]
  - *City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run Condition Assessment (Baker, 2013)*
- Task 4 – Identify problem areas and suggest solutions.
  - *Task 4 Evaluation Criteria Scoring Systems (CH2M HILL, 2014)*

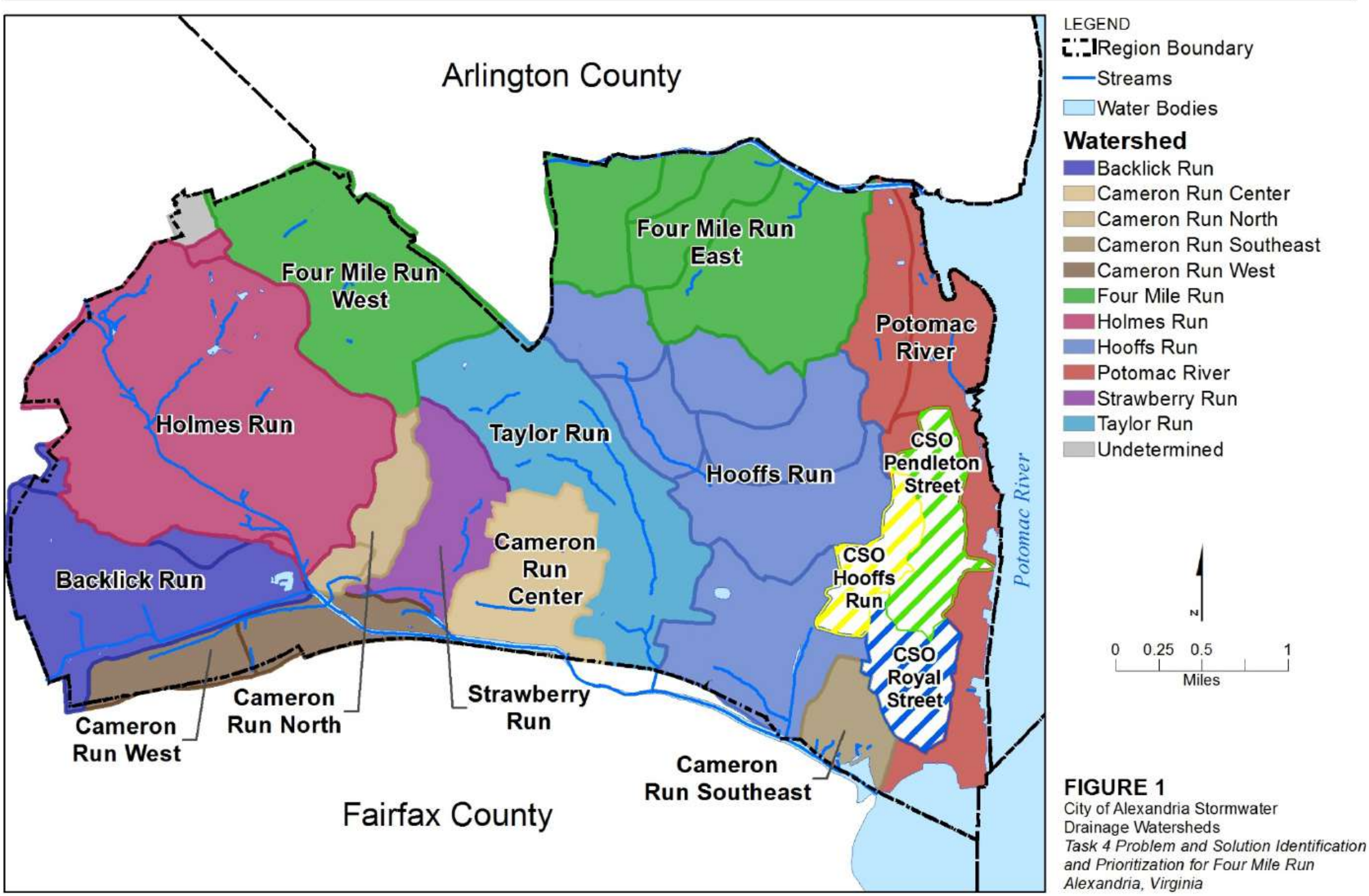
1.2 Objectives

Tasks 1 through 3 focused on model development and capacity analysis of the existing system. The purpose of Task 4 is to identify and prioritize problems modeled during the Task 2 capacity analysis and to suggest and prioritize conveyance, storage, and green infrastructure (GI) solutions to resolve the identified capacity limitations.

This report describes the methodology and results of Task 4 for the stormwater collection system in the Four Mile Run Watershed. Figure 1-1 presents the City's stormwater drainage watersheds.

[1] Though originally intended to improve data quality where the model predicted capacity limitations, the scope of Task 3 was expanded, and field survey was completed before Task 2 to fill data gaps and to improve the model development process.

FIGURE 1-1
Stormwater Drainage Watersheds, City of Alexandria, Virginia
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



SECTION 2
Approach

To identify and prioritize problems and solutions, several distinct steps were included as follows:

- Identification and prioritization of problems
- Development and modeling of solutions
- Prioritization of solutions
- Development of watershed-wide scenarios

This section describes this approach, which is broken into two major components: prioritization and modeling.

2.1 Prioritization

The focus of Task 4 is prioritization of problem areas based on Task 2 modeling results, development of solutions to resolve the problem areas, then prioritization of those solutions. Before beginning the Task 4 analysis, City staff and CH2M HILL and Michael Baker consultants convened in a workshop on November 14, 2012 to discuss the objectives, approach, and desired outcomes of this phase of the project. The major objectives of the workshop were to define the prioritization process, identify the key evaluation criteria for scoring and ranking problems and solutions, and define relative criteria weights. The following prioritization process is similar for both problems and solutions:

- **Define evaluation criteria**: Evaluation criteria for problems and solutions were defined during the Task 4 workshop with input from City Engineering & Design, Office of Environmental Quality, and Maintenance Divisions of Transportation and Engineering Services staff. These criteria, which are summarized in this report, were used to assess the severity of problems and the benefit of solutions.

- **Weight evaluation criteria**: Each evaluation criterion was assigned a weight (0 to 100) by Task 4 workshop participants. The weights quantify the relative importance of each evaluation criteria and build a defensible foundation for problem and solution ranking.

- **Define scoring system**: A scoring system was developed for each evaluation criteria. This provided a method for ranking problems and solutions within evaluation criteria. Scoring systems for problem area and solution evaluation criteria are defined in this report.

- **Score and rank alternatives**: Problems and solutions were scored and ranked using the evaluation criteria scoring systems, which are described in the TM, *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014) and include:

  - *Score and Rank Problems:* A score of 0 through 10 was assigned to stormwater junctions in the modeled system for each evaluation criteria. Weights were then applied to the score calculated for each evaluation criteria to come up with an overall weighted score for each junction. The overall score was used to rank problems, then high-priority problem areas were identified as groupings of hydraulically connected junctions and pipes. Solutions were investigated for the highest-priority problem areas.

  - *Score and Rank Solutions*: Solutions were developed for high-priority problem areas identified in the previous step. A score of 0 through 10 was assigned to solutions for each evaluation criteria. Then the weights were applied to the score calculated for each evaluation criteria to calculate an overall weighted benefit score. Solutions were ranked based on the overall score as well as the cost/benefit score, which is the overall benefit score divided by the capital cost of the solution. The solution evaluation is presented at the end of this report.

- **Perform “what-if” analysis to refine process**: After completing the prioritization, the process was examined to ensure the results met the City’s expectations. The outcome of this step was the inclusion of a 22 percent minimum threshold for flood volume reduction (any project that produced less than 22 percent reduction in volume of flooding was eliminated) to help focus the solution identification process. This threshold was selected by City staff based on best engineering judgment.

- **Evaluate watershed-wide scenarios**: Once individual solutions were evaluated, the solutions were grouped into three alternative watershed-wide scenarios. The scenarios were scored by summing scores and costs of individual projects for comparison. The purpose of taking this watershed-wide look was to evaluate the solutions in a holistic, system-wide manner to evaluate the impacts of implementing various solutions across the system. This also supports the selection of solutions that will provide the greatest benefit for the least cost.

2.1.1 Problem Area Evaluation

The problem area evaluation focused on identifying flooding problems that are extreme and/or in proximity to critical facilities. Though model results were presented for pipes; and not junctions in the Stormwater Capacity Analysis (Task 2), flooding occurs at a junction and not along the length of the pipe. Therefore, stormwater junctions in the hydraulic model, not pipe segments, were scored for each of the problem area evaluation criteria. Raw scores for each criterion ranged from 0 to 10, 0 indicating the junction is not a priority and/or the evaluation criteria is not applicable, and 10 indicating the junction is a high-priority. The problem area evaluation criteria includes the following:

- Urban drainage and flooding
- Identification of problems by the public
- Identification of problems by city staff
- Proximity to critical infrastructure
- Proximity to critical roadways
- Opportunity for overland relief

Detailed descriptions of the problem scoring systems used in this evaluation are provided in the TM, *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014). The weighted score was computed using the raw score and normalized percent weight. Evaluation criteria and weights developed and agreed upon during the Task 4 Workshop are presented in Table 2-1.

TABLE 2-1
Problem Area Evaluation Criteria and Weights
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area Evaluation Criteria	Weight	Normalized % Weight
Urban Drainage and Flooding	90	23.1
Public ID of Problem	73	18.8
City Staff ID of Problem	75	19.3
Proximity to Critical Infrastructure	58	14.9
Proximity to Critical Roadways	38	9.8
Opportunity for Overland Relief	55	14.1
Total	**389**	**100**

Notes:
ID = Identification

After computing the weighted score for each junction, high-priority problem areas were identified as hydraulically connected groupings of junctions and pipes for the junctions with scores in the top 33 percent of scores over 0. Scoring was based on results from the Task 2 model of the 10-year, 24-hour storm generated using the existing intensity-duration-frequency (IDF) curve. The results of the problem area evaluation are presented in Section 3, Problem Identification.

The goal of delineating high-priority problem areas was to identify groupings of stormwater pipes causing capacity limitations so that conveyance, storage, and GI solutions could be developed for the area. This task was accomplished by starting with the highest-ranked junction score. This score indicated it was the worst problem based on the problem area identification evaluation criteria, and based on the review of the surrounding drainage network and model results to identify the pipes and junctions related to that high problem score. A polygon surrounding all the pipes related to the capacity limitation was digitized in ArcMap and was assigned a unique identifier. After completing this process for the highest-ranked junction score, the network and model results for the next-highest score were examined, and a new problem area was digitized. However, if the junction with the next highest-score was already captured in the first high-priority area, it was skipped. This process was repeated for junctions with a score above 35, or the top 33 percent of junctions with a score over 0. Flooding at locations outside of the high-priority problem areas were either flooding at isolated structures, or did not score high based on the problem area scoring criteria. These flooding problems were not addressed by solutions in this project.

2.1.2 Solution Evaluation

Solutions were developed to resolve or improve capacity limitations in the highest-priority problem areas. Three different technologies were evaluated: conveyance, storage, and GI. Modeling results, described in detail in the following sections, were used in conjunction with additional data from the City (for example, geospatial data on roads and critical infrastructure, capital improvement plans, maintenance plans) to score solutions for each of the following solution evaluation criteria:

- Urban drainage and flooding
- Environmental compliance
- EcoCity goals and sustainability
- Social benefits
- Integrated asset management
- City-wide maintenance implications
- Constructability
- Public acceptability

Detailed descriptions of the solution scoring systems used in this evaluation are provided in the TM entitled *Task 4 Evaluation Criteria Scoring Systems* (CH2M HILL, 2014). The weighted score was computed using the raw score and normalized percent weight. Table 2-2 presents the evaluation criteria and weights agreed upon during the Task 4 workshop.

TABLE 2-2
Solution Evaluation Criteria and Weights
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Solution Evaluation Criteria	Weight	Normalized % Weight
Urban Drainage and Flooding	95	17.1
Environmental Compliance	93	16.8
EcoCity Goals and Sustainability	50	9.0
Social Benefits	40	7.2
Integrated Asset Management	73	13.2
City-wide Maintenance Implications	90	16.2
Constructability	60	10.8
Public Acceptability	53	9.6
Total	**554**	**100**

2.2 Modeling

To support the Task 4 analysis, the Four Mile Run watershed stormwater capacity was analyzed with commercially available and public domain computer models widely used and industry-accepted. The details of the hydrologic and hydraulic modeling are documented in the Task 2 TM, *Stormwater Capacity Analysis for Four Mile Run Watershed, City of Alexandria, Virginia* (CH2M HILL & Baker, 2016). The existing conditions model of the 10-year, 24-hour design storm based on the City's existing IDF curve served as the basis for modeling in the Task 4 analysis.

Figure 2-1 and Table 2-3 present the Task 2 results for reference.

TABLE 2-3
Summary of Task 2 Model Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

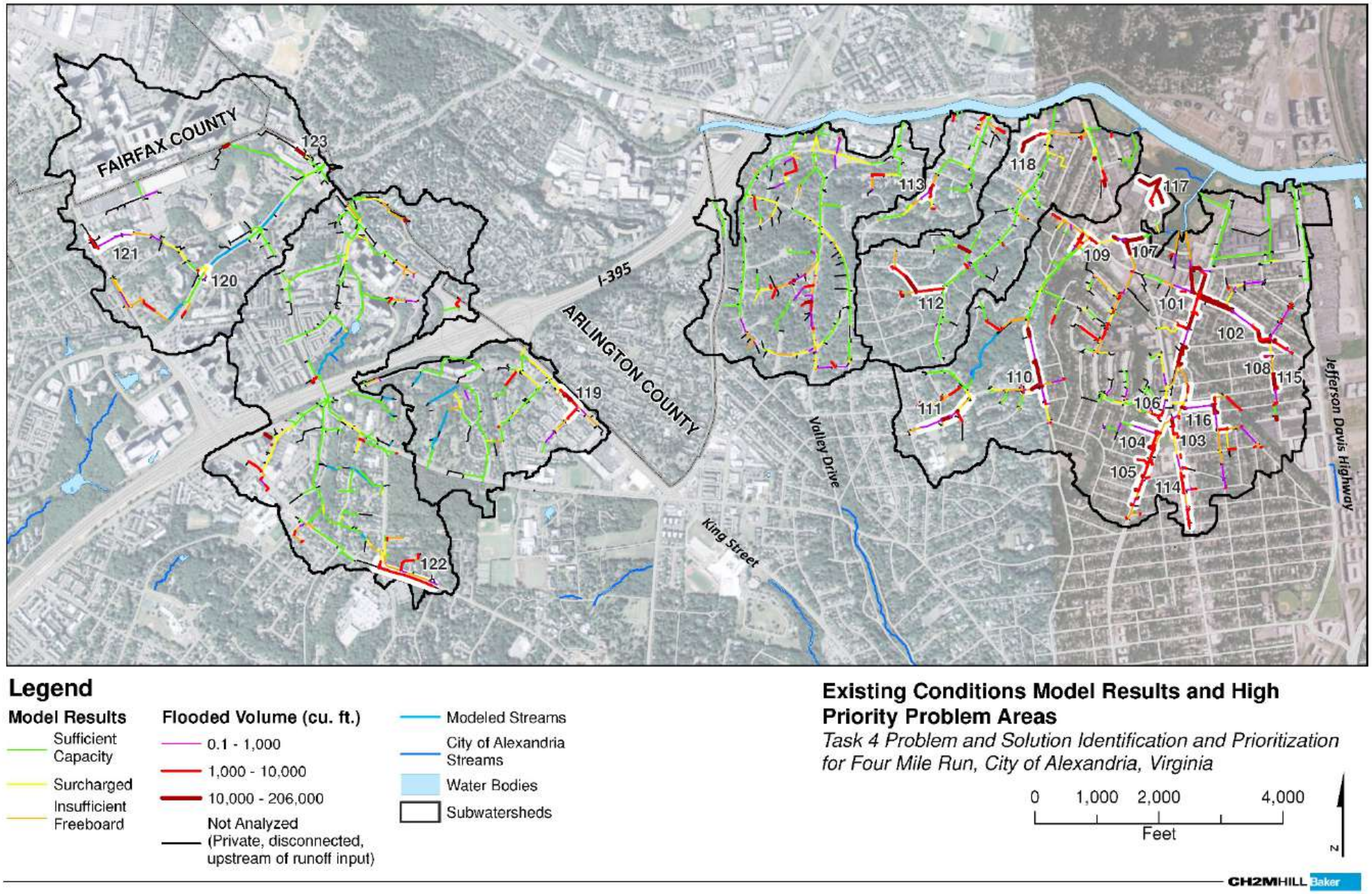
	Existing Conditions Results				
	Conduit Count	**Conduit Length (LF)**	**Percent of Total Length (%)**	**Total Duration (hrs)**	**Total Volume (ft^3)[a]**
Sufficient Capacity	656	72,570	46	-	-
Surcharged[b]	271	22,216	14	2,262	-
Insufficient Freeboard	282	25,337	16	-	-
Flooded	454	38,634	24	746	3,257,585

Notes:

Results presented for pipe segments are based on capacity at upstream end of pipe.

[a] Flooded volume includes volume flooded at upstream end of the conduit.
[b] Duration of surcharged flow includes time during which conduits have insufficient freeboard or are flooded at upstream end only.
ft^3 – cubic feet
hrs – hours
LF – linear feet

FIGURE 2-1
Existing Conditions Model Results and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



2.2.1 Baseline Improvements and Major Capacity Solutions

In Hooffs Run, the first watershed analyzed for this study, several baseline improvements and major capacity solutions were identified and addressed before evaluating solutions in the rest of the system. The goal of identifying baseline improvements was to remove hydraulic limitations that may have negatively impacted the ability to model solutions. A similar evaluation was conducted for Four Mile Run to determine whether baseline improvements and major capacity solutions were needed.

Profiles of the Four Mile Run existing conditions model results were reviewed to identify significant changes in diameter or slope, over relatively short distances where there was also a sudden increase in the hydraulic grade line. In addition to reviewing the profiles, the data source for invert and diameter information were reviewed. There were no locations identified in the Four Mile Run watershed that required baseline improvements. In addition, no locations were identified within the Four Mile Run watershed where extreme capacity limitations caused long backwater conditions and substantial flooding in the system. Therefore, there was no need for developing solutions for major capacity problems.

2.2.2 Alternative Solutions

The purpose of this task was to identify and evaluate corrective measures that could be undertaken to reduce flooding and improve stormwater quality through the use of GI practices. In addition, there is the potential to achieve other ancillary benefits such as improved aesthetics, urban-heat-island reduction, and carbon capture through context-sensitive solutions. Potential solutions were developed for each of the following project types or technologies, where applicable:

- Conveyance improvements
- Storage (modeled as underground storage, but could also be implemented as above ground storage or other conventional stormwater management approaches)
- GI

The goal of the conveyance solutions was to evaluate the impact of increased conveyance capacity on flooding and surcharge in the high-priority problem areas. Conveyance improvements were modeled in xpswmm by increasing pipe diameter up to 0.1-foot below ground surface (bgs). The invert elevations and alignment of existing pipes were not altered, so pipe slope did not change from existing conditions. Because the goal of this evaluation was not to design solutions but to evaluate potential strategies and technologies, more detailed design will be required to develop fully implementable projects, including adjusting pipe shapes, providing parallel pipes, and providing for adequate ground cover.

The storage solutions involved evaluating the potential for new detention or retention facilities or offline storage for high-priority problem areas. Because of the dense urban development prevalent in the City, conventional stormwater management (SWM) practices were assumed to be limited to off line subsurface storage facilities in the hydraulic model. Opportunities for subsurface storage were identified in open spaces (such as parking lots, green spaces, and grassed medians), with a preference for City-owned properties. Storage was modeled in xpswmm using storage nodes and weirs to model the overflow from a manhole into storage. The maximum storage size was determined by measuring the surface area of the open space available for storage and estimating the storage depth based on the manhole to which the storage system would be dewatered. It was assumed that storage should be a minimum 3 feet deep and a maximum 10 feet deep to maintain reasonable construction costs. Additionally, storage was only considered if gravity dewatering to a manhole within 1,000 feet was possible. Storage facilities would not be dewatered until the system had capacity to convey the stored flow. Because the focus of the modeling was to identify capacity limitations and flooding problems, storage dewatering was not evaluated in this analysis.

GI was evaluated at three different implementation levels: low, medium, and high. In the xpswmm model, GI was modeled by reducing impervious cover in model subcatchments. The low implementation level was modeled as a 10 percent reduction in impervious area, the medium at a 30 percent reduction, and the high at a 50 percent reduction. During development of the modeling approach, soil and depression storage parameters were evaluated for sensitivity in the model. Ideally, these parameters would be adjusted to more accurately represent the physics of GI performance in the field. However, this level of detailed modeling was beyond the scope of this study, and infiltration parameters were not altered when modeling GI.

Table 2-4 describes the modeling approach and basic assumptions for each of the solution technologies. Solutions developed for each high-priority problem area detailed in Section 4, Solution Identification.

TABLE 2-4
Description of Solution Modeling Approaches and Assumptions
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Solution Technology/Strategy	Modeling Approach	Basic Assumptions
Conveyance	Increase Pipe Diameter	Use existing slope and pipe alignment. Increase pipe diameter to a maximum of 0.1 foot bgs. Add barrels as necessary.
Storage	Add storage node with weir to convey flow into storage	Storage depth is between 3 feet and 10 feet bgs. Gravity dewatering is required. A 20-foot-long weir to storage with discharge coefficient of 3 is required. Only surcharged flow will be sent to storage.
GI	Decrease catchment impervious area	Low implementation: 10 percent reduction in impervious area. Medium implementation: 30 percent reduction in impervious area. High implementation: 50 percent reduction in impervious area.

Solution alternatives were modeled in xpswmm. The basis for the solution models was the Task 2 existing conditions model.

Alternative solutions were evaluated in five different models, one for each technology and strategy:

- Conveyance solutions model
- Storage solutions model
- Low GI (LGI) implementation model
- Medium GI (MGI) implementation model
- High GI (HGI) implementation model

This approach has limitations because several projects are in proximity to one another; therefore, the hydraulics are inextricably linked. However, because of the number of solutions and technologies being evaluated, evaluating each project independently was not within the scope of the analysis.

SECTION 3

Problem Identification

The purpose of the problem identification task was to assign a score to structures in the stormwater drainage network so that high-priority problem areas could be identified. Solution alternatives were developed for high-priority problem areas in the Four Mile Run watershed. Junctions were scored for each of the problem area evaluation criteria. Table 3-1 shows the distribution of scores across the 3,010 stormwater junctions that were modeled in Four Mile Run. These results were generated using the Task 2 existing condition model (existing IDF and existing boundary conditions). Figure 3-1 provides a map of the junction scores.

TABLE 3-1
Four Mile Run Problem ID Scores
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem ID Score	Count of Junctions	% of Total
0	1,753	58.2
0.1 – 20	795	26.4
20.1 – 30	222	7.4
30.1 – 40	162	5.4
40.1 – 50	62	2.1
>50	16	0.5
Total	**3,010**	**100**

After scoring individual junctions, high-priority problem areas were identified as groupings of hydraulically-connected junctions and pipes in proximity to one another. Initial junction scores and high-priority problem area delineations were based on the existing conditions model results presented in Task 2 TM (CH2M HILL & Baker, 2016). A total of 23 high-priority problem areas were identified in Four Mile Run and are shown on Figure 3-2.

FIGURE 3-1
Four Mile Run Problem Identification Score Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

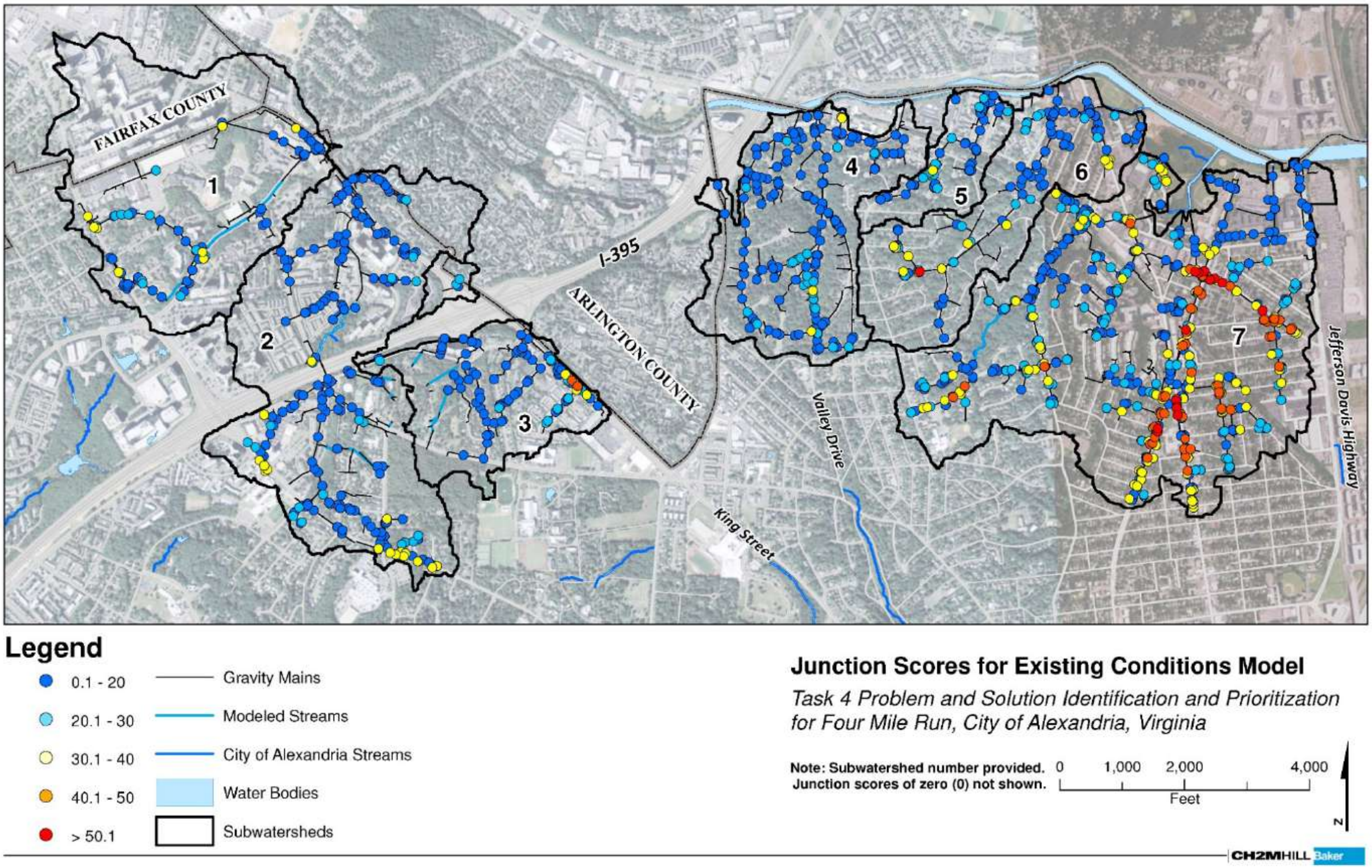
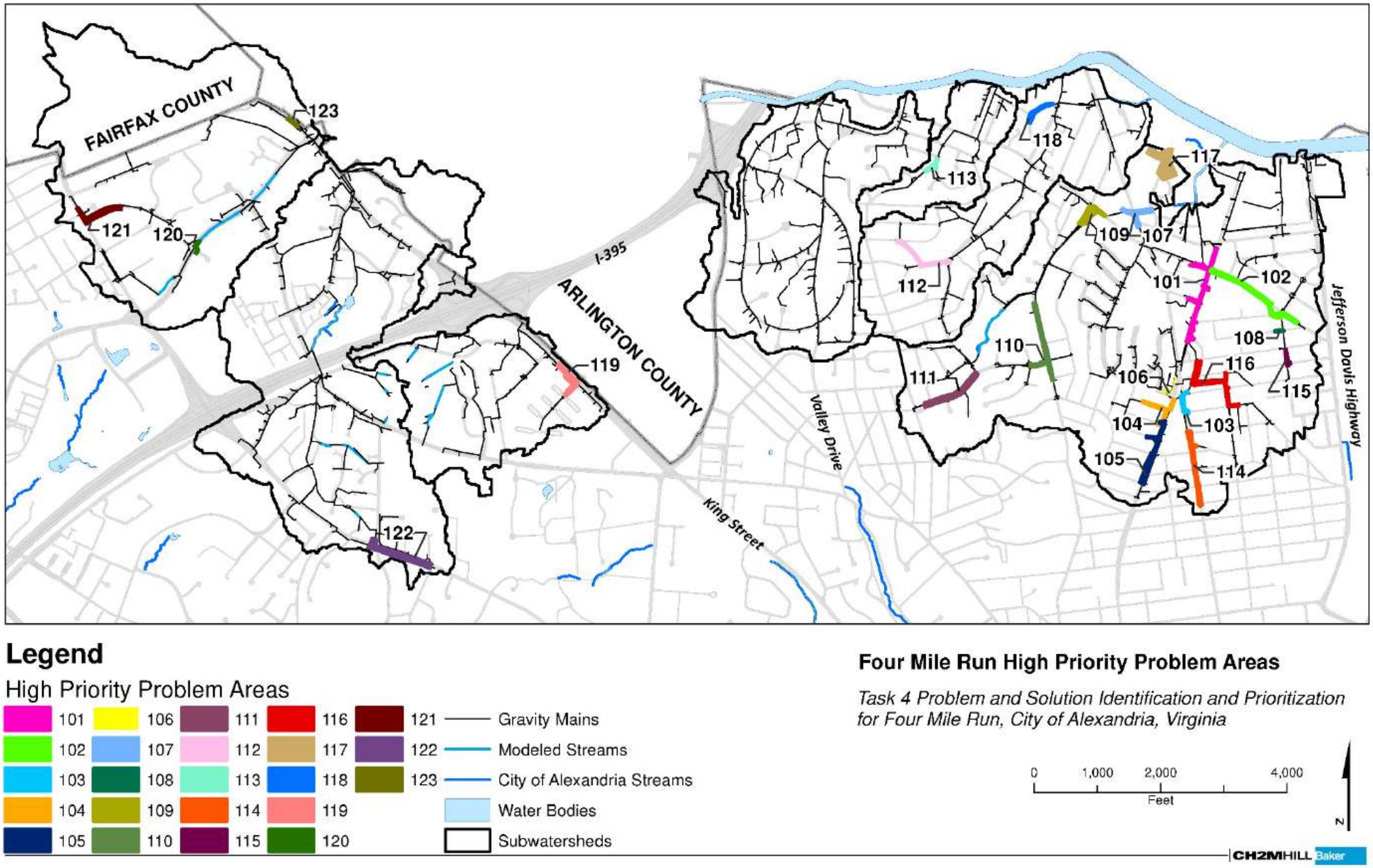


FIGURE 3-2
Location of Four Mile Run High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



SECTION 4

Solution Identification

A suite of solutions, including conveyance, storage, and GI projects, was developed for each problem area. The solution identification process resulted in 109 unique projects for the 23 high-priority problem areas in the Four Mile Run watershed. Because the solutions were focused on the high-priority problem areas, flooding outside those problem areas were not addressed by any of the alternatives. For example in Figure 3-2, there are pipe segments located west of Problem Area 112 near Valley Drive that experience some flooding but the Problem ID scores for this area are lower than the 30-point threshold because there is no critical infrastructure in the area, no historical record of flooding complaints from either the public or the staff, and there is good overland relief. As a result, solutions were not developed for this area. The following sections provide specific solutions developed for each problem area by project type, as well as the model results.

4.1 Conveyance Solutions

The goal of the conveyance solutions was to remove hydraulic limitations in the drainage network by increasing the capacity of the pipes in high-priority problem areas. Because this was a high-level conceptual exercise rather than a design exercise, the pipe alignment and roughness were left unchanged, and capacity was increased solely by increasing the pipe size. In most cases, pipe shape was not altered except where sufficient capacity could not be achieved because of limited cover or where the existing pipe was a special shape, such as horizontal elliptical pipes. Where there was limited cover, circular pipes were changed to box culverts so that capacity could be increased without daylighting. Special pipe shapes were converted to equivalent-diameter circular pipes to simplify the model and calculations.

The conveyance capacity required was estimated using xpswmm. A hydraulic model was used to approximate the unconstrained peak flow in each pipe segment by upsizing pipes to 0.1-foot bgs to maximize diameter without daylighting the pipe, and by increasing the number of barrels by a factor of 2 across the board. The resulting unconstrained peak flow and Manning's equation were used to back-calculate the diameter required for the pipe to flow less than 80 percent full.

In the high-priority problem areas, the required diameter was compared to the existing diameter. Pipes that were smaller than the required pipe size calculated using the unconstrained peak flow were upsized and included in the conveyance project. Pipes that had sufficient capacity under existing conditions were left unchanged. Pipe size was not optimized during this exercise, and runs of pipes were not consistently sized. A summary of the length of pipe and range of pipe sizes included in each conveyance solution is included in Table 4-1. Appendix A contains a table documenting the existing and proposed diameter of each pipe segment.

TABLE 4-1
Summary of Conveyance Projects
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Project ID	Replacement Pipe Size Range and Project Description	Length (LF)
101	CONV-101	10-78 Inch Replacement Sewer Pipe Relief	4,823
102	CONV-102	12-60 Inch Replacement Sewer Pipe Relief	3,818
103	CONV-103	10-84 Inch Replacement Sewer Pipe Relief	1,381
104	CONV-104	10-66 Inch Replacement Sewer Pipe Relief	1,481
105	CONV-105	10-66 Inch Replacement Sewer Pipe Relief	1,938
106	CONV-106	12-54 Inch Replacement Sewer Pipe Relief	835
107	CONV-107	15-54 Inch Replacement Sewer Pipe Relief	1,855

TABLE 4-1
Summary of Conveyance Projects
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Project ID	Replacement Pipe Size Range and Project Description	Length (LF)
108	CONV-108	12-42 Inch Replacement Sewer Pipe Relief	460
109	CONV-109	12-96 Inch Replacement Sewer Pipe Relief	2,250
110	CONV-110	10-54 Inch Replacement Sewer Pipe Relief	2,891
111	CONV-111	10-42 Inch Replacement Sewer Pipe Relief	1,859
112	CONV-112	12-54 Inch Replacement Sewer Pipe Relief	1,462
113	CONV-113	15-36 Inch Replacement Sewer Pipe Relief	751
114	CONV-114	10-48 Inch Replacement Sewer Pipe Relief	2,042
115	CONV-115	12-48 Inch Replacement Sewer Pipe Relief	580
116	CONV-116	10-78 Inch Replacement Sewer Pipe Relief	2,685
117	CONV-117	12-36 Inch Replacement Sewer Pipe Relief	1,161
118	CONV-118	12-42 Inch Replacement Sewer Pipe Relief	664
119	CONV-119	12-60 Inch Replacement Sewer Pipe Relief	1,176
120	CONV-120	15-48 Inch Replacement Sewer Pipe Relief	492
121	CONV-121	12-30 Inch Replacement Sewer Pipe Relief	1,396
122	CONV-122	12-30 Inch Replacement Sewer Pipe Relief	1,621
123	CONV-123	12-36 Inch Replacement Sewer Pipe Relief	783

A map of the existing conditions model results is provided on Figure 4-1 for reference, and a map of the conveyance solution model results is provided on Figure 4-2.

FIGURE 4-1
Existing Conditions Model Results and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

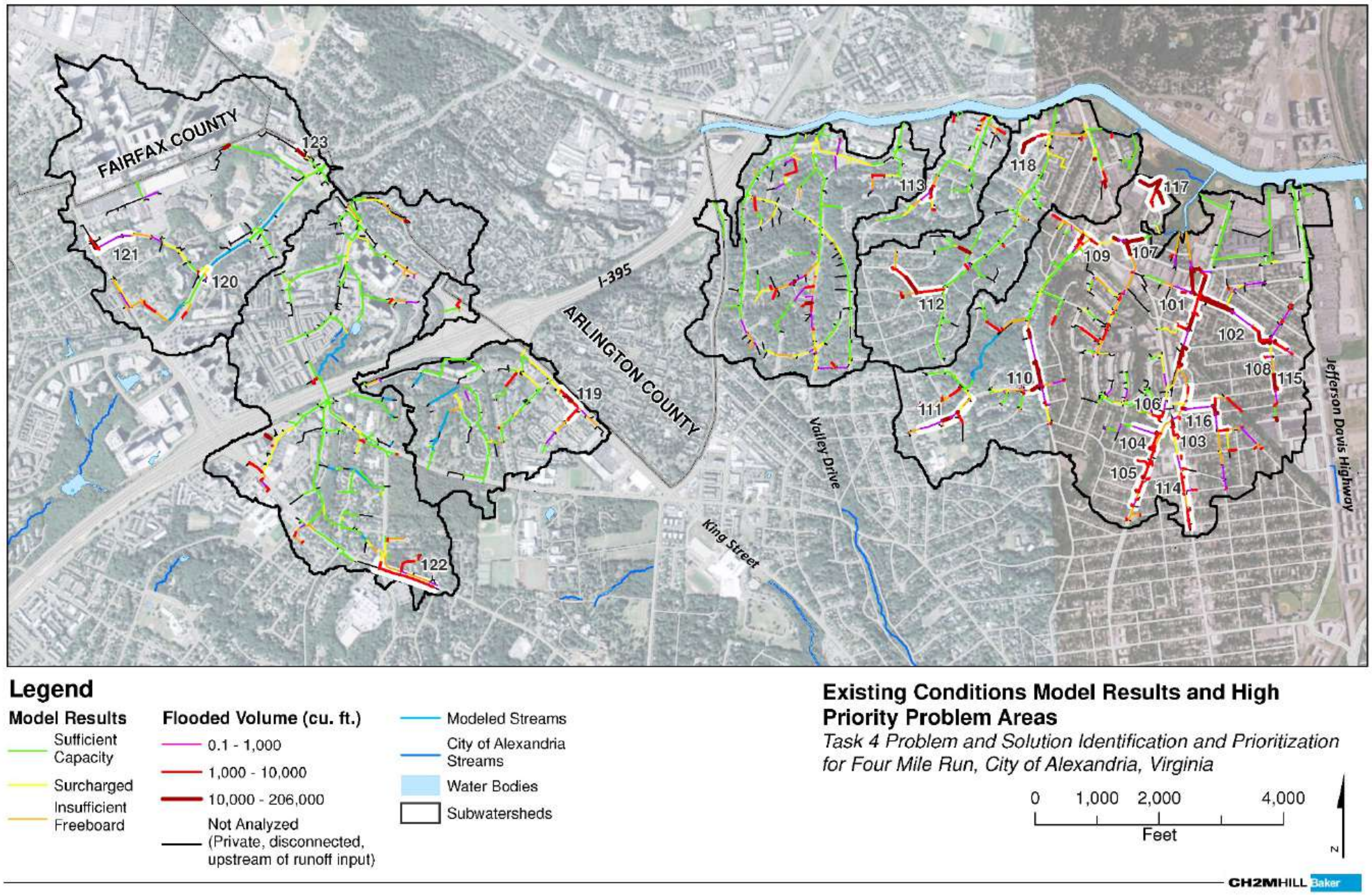
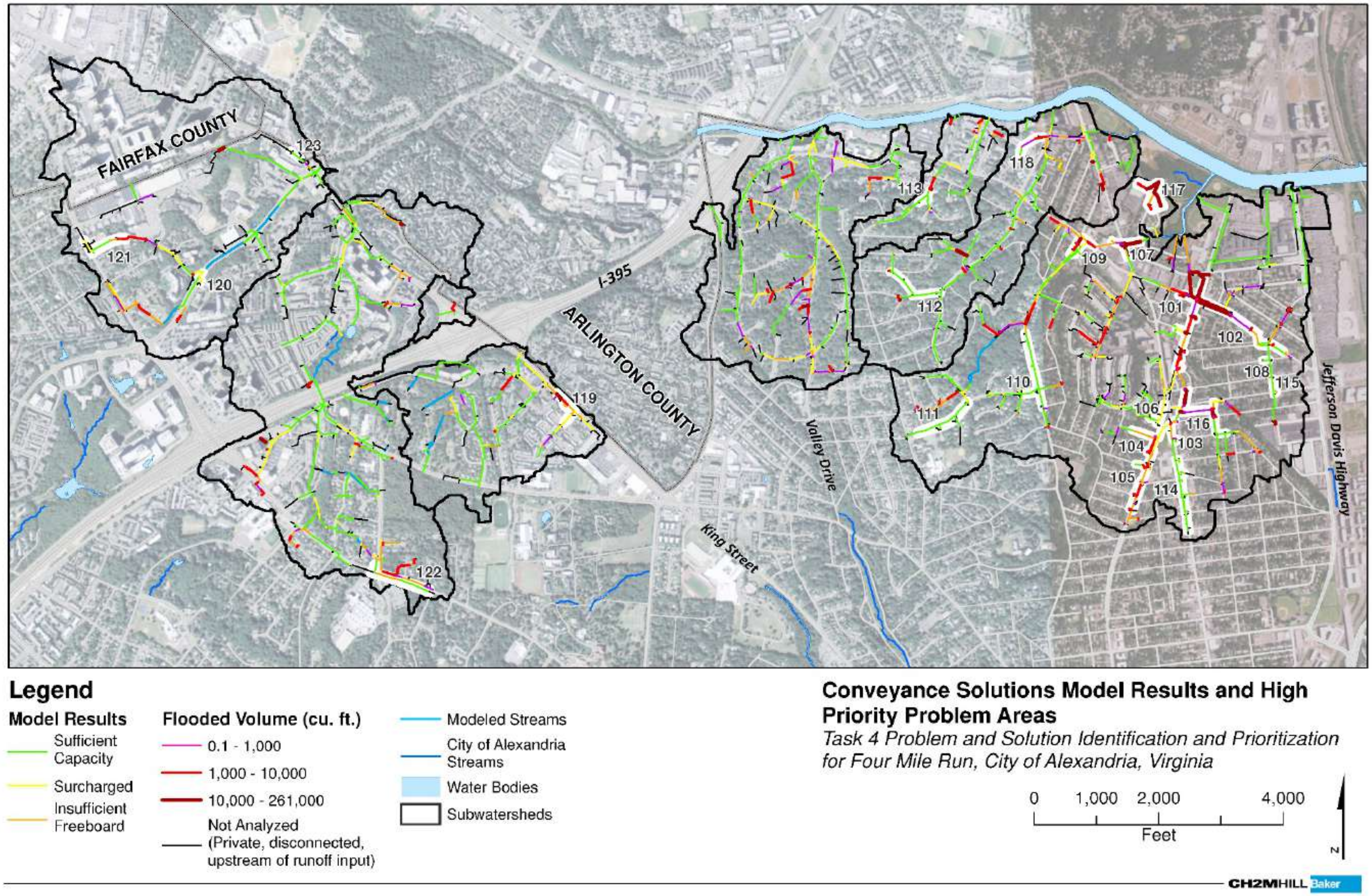


FIGURE 4-2
Conveyance Solutions Model Results and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



The conveyance solutions lessened or resolved some localized problems within the high-priority problem areas; however, some of the peak flow and volume is passed downstream creating new flooding and capacity limitations. Table 4-2 summarizes the model results for the existing conditions model, which is the starting point for the conveyance solution model and the conveyance solutions. Side-by-side comparison shows that overall flooding is eliminated in about 8 percent of the system by length. The total duration of flooding decreases 28 percent and the total volume flooded is reduced by over 21 percent, indicating the severity of flooding is substantially reduced.

TABLE 4-2
Summary of Existing Conditions Model and Conveyance Solutions Model Results in Four Mile Run
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

	Existing Conditions Results				Conveyance Solutions Results			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	72,570	46	-	-	85,377	54	-	-
Surcharged[a]	22,216	14	2,262	-	23,429	15	1,179	-
Insufficient Freeboard	25,337	16	-	-	23,629	15	-	-
Flooded	38,634	24	746	3,257,585	26,467	16	539	2,585,654

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits are surcharged, have insufficient freeboard, or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

Flooding outside of the high-priority problem areas was not addressed by the proposed solutions; therefore, a summary of the modeling results within the high-priority problem areas is provided in Table 4-3. Not including Problem Areas 107 and 116 with increased flood volumes, the average flood volume was reduced by 75 percent within the high-priority problem areas. The disadvantage of the conveyance solutions is that, while increasing pipe capacity reduces flooding in the problem area, it increases peak flows that can create or increase flooding downstream. Peak flow was increased for all 23 high-priority problem areas, though this increase was much higher in some problem areas, ranging from a 3 percent increase in Problem Area 120 to a 238 percent increase in Problem Area 117.

TABLE 4-3
Conveyance Solutions Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
	Existing Conditions Model Results	Conveyance Solutions Model Results	Percent Reduction (%)[a]	Existing Conditions Model Results	Conveyance Solutions Model Results	Percent Increase (%)[b]
101	3.542	2.097	41	107.8	124.1	15
102	2.167	1.769	18	219.0	146.0	-33
103	0.347	0.026	93	104.0	258.4	149
104	0.448	0.053	88	66.2	152.0	130
105	0.653	0.120	82	53.4	102.5	92
106	0.130	-	100	78.3	98.6	26
107	3.655	4.367	-19	297.6	298.6	0
108	0.010	-	100	46.8	96.3	106

TABLE 4-3
Conveyance Solutions Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
	Existing Conditions Model Results	Conveyance Solutions Model Results	Percent Reduction (%)[a]	Existing Conditions Model Results	Conveyance Solutions Model Results	Percent Increase (%)[b]
109	0.288	0.254	12	362.5	408.4	13
110	1.284	-	100	83.6	226.0	170
111	0.279	-	100	62.4	109.2	75
112	0.193	-	100	150.4	203.0	35
113	0.129	-	100	60.4	85.3	41
114	0.315	-	100	38.6	90.6	135
115	0.342	-	100	33.5	72.2	115
116	1.160	1.315	-13	138.2	229.5	66
117	1.335	1.275	4	10.0	33.8	237
118	0.417	0.098	76	15.4	20.3	32
119	0.242	0.149	38	75.3	83.1	10
120	0.005	-	100	185.4	190.2	3
121	0.070	0.055	21	32.2	37.7	17
122	0.142	-	100	13.4	28.7	114
123	0.099	-	100	65.3	100.1	53
		Average	**67**		**Average**	**70**

Notes:
[a] Negative value in Percent Reduction column indicates an increase in flood volume
[b] Negative value in Percent Increase column indicates a decrease in peak flow
MG = million gallons
cfs = cubic feet per second

The approach of sizing the conveyance projects based on the unconstrained peak flow allowed all conveyance projects to be run in a single iteration. Since stormwater gravity main diameters were increased to convey the largest potential peak flow, the impact of increasing capacity upstream was incorporated into the sizing of any downstream conveyance solutions. However, evaluating all of the conveyance projects in a single model run has limitations. Because the problem areas are interconnected, modeling all solutions in a single run does not allow each solution to be viewed independently. Several problem areas are in proximity to one another; therefore, increasing the capacity at one location impacts the hydraulics in nearby problem areas, either by adding additional flow downstream or potentially increasing backwater for adjacent problem areas.

For example, Problem Area 116, located near the intersection of Dewitt Avenue and Hume Avenue, is downstream of Problem Areas 103, 104, 105, and 114. Because Problem Area 116 is directly downstream of other problem areas, adding conveyance solutions to the model for all problems at once causes the peak flow and volume passing through Problem Area 116 to be greater than if this area was modeled separately, potentially decreasing the modeled performance of the solutions. This is clear when reviewing the results presented in Table 4-3. The flood volume increased from 1.16 MG to 1.32 MG in Problem Area 116.

Additionally, modeling all of the conveyance projects at once causes substantial flooding downstream of these closely located projects. The combined effect of modeling all of these conveyance projects at once is that a very large peak flow and volume are able to pass through areas that previously had capacity limitations, which only causes a capacity limitation downstream.

4.2 Storage Solutions

Conventional SWM solutions considered in this study include detention facilities and ordinance changes. Because of the challenges of translating ordinance changes into hydrologic and hydraulic parameters, only storage solutions were modeled in xpswmm. Ordinance changes were reviewed during the Hooffs Run Task solutions analysis and are summarized in *Task 4: Problem and Solution Identification and Prioritization for Hooffs Run, Alexandria, Virginia* (CH2M HILL, 2016).

The storage solutions goal was to add storage to the stormwater drainage network to decrease peak flow and volume during the modeled rainfall event. Because of the urban nature of the study area, it was assumed that to provide a sufficient storage volume, detention facilities would have to be below grade vaults. Several constraints guided the siting of potential storage solutions, including the following:

- Depth of storage facility should not exceed 10 feet to minimize excavation costs
- Storage will be dewatered by gravity to a manhole less than 1,000 feet downstream to eliminate pumping costs
- Minimum storage depth should be 3 feet, measured from the storage inlet to the storage outlet
- Only surcharged flow will be sent to storage

The first step in developing storage solutions was to identify open space that may be available for subsurface storage vaults with preference for City-owned property. This primarily included parking lots, green space (for example, parks, school yards, playing fields, church yards), and grassed medians or boulevards. These storage areas were identified using aerial imagery and were deemed feasible using drainage network data (gravity main locations and inverts) and topographic data. Storage areas meeting the constraints described were identified for 17 of the high-priority problem areas; no storage opportunities were identified for Problem Areas 105, 106, 108, 112, 115, or 116; multiple storage areas were identified in Problem Areas 101, 102, 107, 109, 113, 117, 121,and 122. A map of these locations is provided on Figure 4-3. Table 4-4 summarizes the storage depth, area, and volume. More detailed maps of the storage solutions locations are provided in Appendix B.

FIGURE 4-3
Storage Solution Locations and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

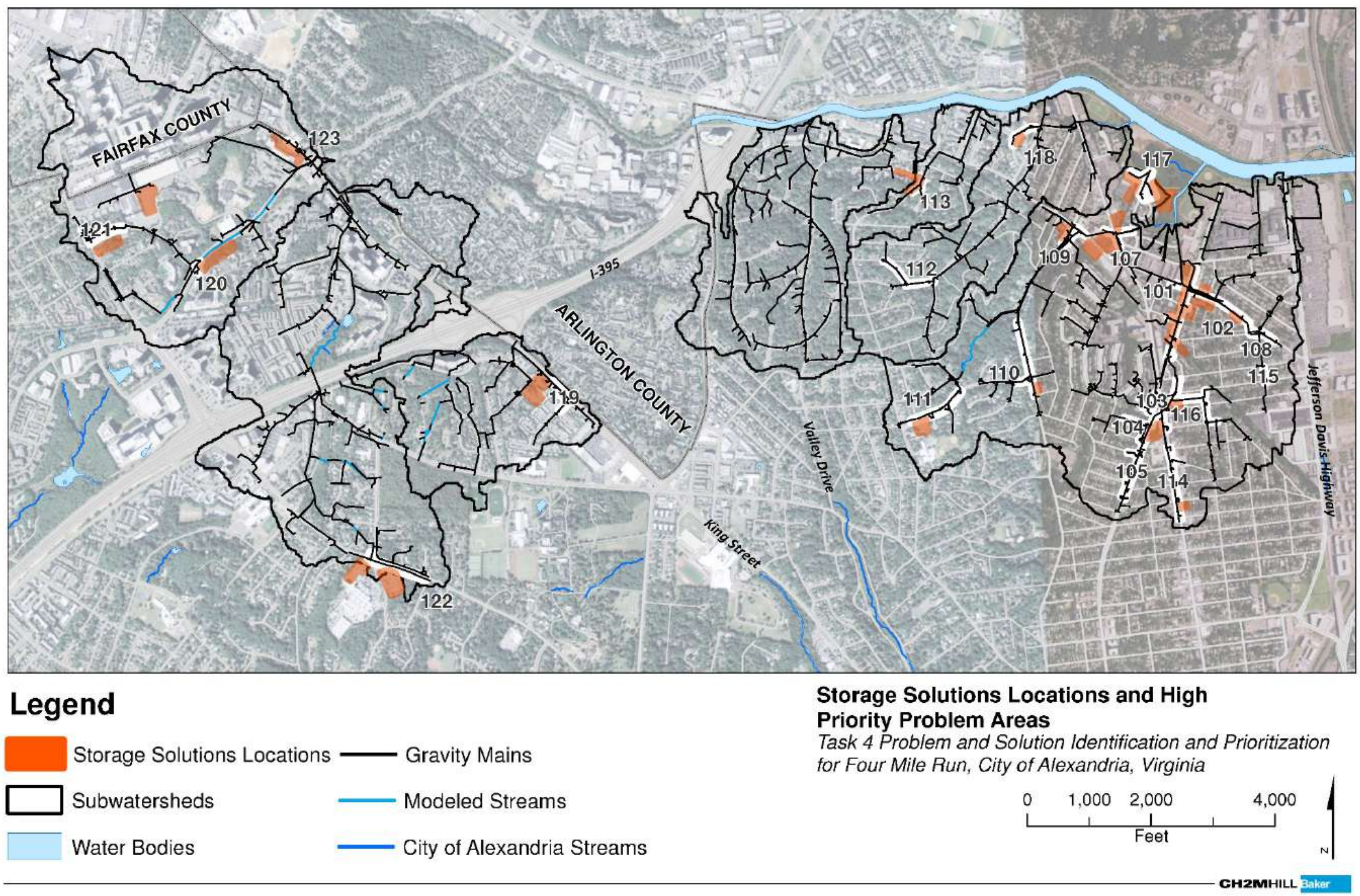


TABLE 4-4
Storage Solutions Summary
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Storage ID	Max Depth (ft)	Total Storage Area Available (ft^2)	Total Volume Available (ft^3)	Total Volume Required (ft^3)
101	STOR-101	6.4	86,564	410,648	261,577
102	STOR-102	9.5	26,274	160,378	259,820
103	STOR-103	4.4	13,242	57,908	57,473
104	STOR-104	4.2	30,052	127,422	73,174
107	STOR-107	4.7	69,369	301,837	503,117
109	STOR-109	10.0	44,998	349,588	35,920
110	STOR-110	10.0	6,627	66,267	175,671
111	STOR-111	10.0	31,967	319,668	31,503
113	STOR-113	10.0	12,993	96,177	15,056
114	STOR-114	3.0	6,214	18,713	43,544
117	STOR-117	5.9	100,225	485,470	79,082
118	STOR-118	3.5	5,978	20,761	58,930
119	STOR-119	3.0	73,518	224,229	32,321
120	STOR-120	10.0	64,347	643,472	9,017
121	STOR-121	10.0	98,809	917,048	14,049
122	STOR-122	8.3	91,632	493,705	14,439
123	STOR-123	10.0	31,517	315,174	12,613

Notes: No storage opportunities were identified for problem areas 105, 106, 108, 112, 115, or 116.
ft^2 – square feet

A map of the results of the storage solution model run is provided on Figure 4-4, and a summary of the results is provided in Table 4-5.

FIGURE 4-4
Storage Solutions Model Results and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

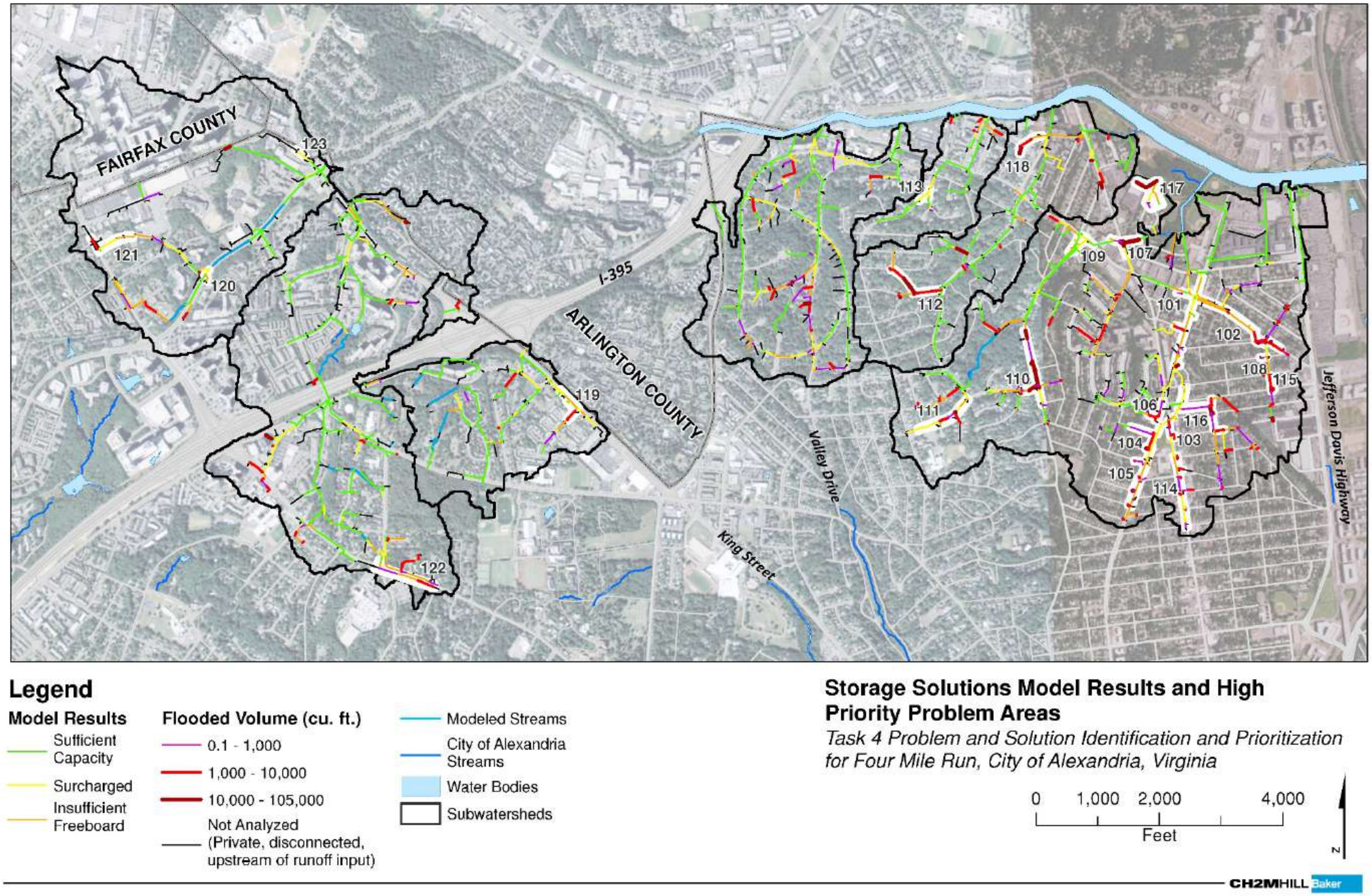


TABLE 4-5
Summary of Existing Conditions Model and Storage Solutions Model Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

	Existing Conditions Results				Storage Solutions Results			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	72,570	46	-	-	77,900	49	-	-
Surcharged[a]	22,216	14	1,600	-	27,257	17	1,085	-
Insufficient Freeboard	25,337	16	-	-	27,546	17	-	-
Flooded	38,634	24	746	3,257,585	26,054	16	230	1,489,604

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits are surcharged, have insufficient freeboard, or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

Overall, the storage solutions decrease the total volume of flooding in the watershed by more than 54 percent, and the duration of flooding is decreased by more than 69 percent. Flooding is eliminated in about 8 percent of the system (by length), and a portion of these pipes contribute toward the increase in the length of surcharged pipes in the solution results. The total duration of surcharge in the system actually decreases by 515 hours; however, the length of surcharged pipe is significantly increased. Flooding outside of the high-priority problem areas was not addressed by the proposed solutions; therefore, a summary of the modeling results within the high-priority problem areas is provided in Table 4-6. On average, the flood volume was reduced by 60 percent within the high-priority problem areas, and the peak flow was reduced by over 14 percent.

TABLE 4-6
Storage Solutions Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
	Existing Conditions Model Results	Storage Solutions Model Results	Percent Reduction (%)	Existing Conditions Model Results	Storage Solutions Model Results	Percent Reduction (%)[a]
101	3.542	0.133	96	107.8	82.0	24
102	2.167	0.461	79	219.0	99.6	55
103	0.347	0.062	82	104.0	106.7	-3
104	0.448	0.305	32	66.2	58.0	12
105	0.653	0.268	59	53.4	40.9	23
106	0.130	0.084	35	78.3	85.6	-9
107	3.655	1.580	57	297.6	280.1	6
108	0.010	0.005	47	46.8	48.1	-3
109	0.288	-	100	362.5	343.0	5
110	1.284	1.164	9	83.6	83.6	0
111	0.279	0.253	9	62.4	62.4	0

TABLE 4-6
Storage Solutions Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Flood Volume (MG)			Peak Flow at Downstream End of Problem Area (cfs)		
	Existing Conditions Model Results	Storage Solutions Model Results	Percent Reduction (%)	Existing Conditions Model Results	Storage Solutions Model Results	Percent Reduction (%)[a]
112	0.193	0.193	0	150.4	150.4	0
113	0.129	-	100	60.4	49.7	18
114	0.315	0.109	65	38.6	38.5	0
115	0.342	0.334	2	33.5	34.5	-3
116	1.160	0.512	56	138.2	146.0	-6
117	1.335	0.252	81	10.0	-	100
118	0.417	0.360	14	15.4	11.1	28
119	0.242	0.026	89	75.3	54.8	27
120	0.005	-	100	185.4	158.3	15
121	0.070	0.008	89	32.2	29.2	9
122	0.142	0.019	86	13.4	12.2	9
123	0.099	-	100	65.3	59.3	9
		Average	**60**		**Average**	**14**

Notes: Areas 101, 103, 106, 107, 109, 110, and 116 experienced reductions in flood volumes from upstream storage projects.
[a] Negative value in Percent Reduction column indicates an increase in peak flow

Evaluating all of the storage solutions in a single model is not limited by increases in downstream impacts as the conveyance solutions are. Instead, because of the increased storage capacity at upstream problem areas, the full peak flow may not reach downstream problem areas. In this case, the performance of a problem area may appear to be more favorable than if each problem area were modeled separately.

4.3 Green Infrastructure Solutions

The goal of GI solutions was to reduce the peak runoff rate and runoff volume directed to the storm drainage system by converting impervious surfaces to pervious surfaces. This is accomplished in the field by redirecting runoff from impervious surfaces to GI facilities that detain and infiltrate runoff during rainfall events. Three levels of GI (low, medium, and high) were evaluated in this analysis. In the model, GI was evaluated by reducing the impervious cover in model subcatchments by 10 percent, 30 percent, and 50 percent to represent the low, medium, and high levels of implementation, respectively.

Several GI technologies were considered feasible within the City including:

- **Bioretention and Planters** – planted depression or constructed box with vegetation that typically receives runoff from roadways or rooftop; includes vegetation and soil media over an underdrain and filtration fabric; The City does not typically encourage infiltration. Rain gardens, which typically do not have an underdrain, are not encouraged.
- **Cisterns** – a tank for storing water, typically connected to a roof drain, which can be either above or below ground. Water from a cistern is typically reused or slowly infiltrated into the soil rather than discharged to a storm sewer.

- **Green/Blue Roofs** - a roof of a building that is partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane (green roof) or a roof that is capable of storing and then slowly releasing rainwater (blue roof).
- **Porous Pavement** - paving surfaces designed to allow stormwater infiltration. This may or may not include an underground storage component.
- **Surface Storage** – retrofit of inlets and catch basins to include flow regulators on streets with standard curb and gutter system so that stormwater can be stored within the roadway and slowly released back into the storm sewer system.
- **Amended Soils** – altering soils to improve water retention, permeability, infiltration, drainage, aeration, and/or structure.

These technologies were grouped into GI programs based on land uses where they could be applied. A program combines a set of technologies into an implementation strategy for different types of sites and land use categories. Programs being considered are as follows:

- **Green Streets and Alleys** – includes bioretention/planters and porous pavement combined along the public right-of-way between buildings and roadways. This can include parking lane and curb cuts.
- **Green Roofs** – includes green/blue roofs, sometimes in combination with cisterns.
- **Green Schools** – use of school properties to implement one-to-many GI management strategies, including bioretention/planters, cisterns, green/blue roofs, and porous pavement.
- **Green Parking** – includes bioretention and planters and porous pavement in parking lots.
- **Green Buildings** – use of bioretention and planters, cisterns, and/or downspout disconnection on public or private buildings.
- **Blue Streets** – use short-term surface storage on streets with relatively flat slopes and standard curb and gutter systems.
- **Open Spaces** – use of open spaces to store and/or infiltrate stormwater with the use of a combination of detention, amended soils, bioretention and planters, and/or porous pavement. This may also include stream daylighting where appropriate.

Six GI concepts were developed for the Four Mile Run watershed. These concepts are described in greater detail in Appendix C and demonstrate the applicability of GI technologies in the City.

A drainage area for each high-priority area was identified using the model's hydrologic subcatchments. Because the drainage area includes all model subcatchments upstream of the problem area, where there are problem areas upstream of one another, drainage areas overlap. A map of these drainage areas and problem area locations is provided on Figure 4-5. Table 4-7 summarizes the drainage area, existing impervious area, and impervious area for each level of GI implementation.

TABLE 4-7
Green Infrastructure Solutions Summary
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Existing Drainage Area (acres)	Existing Impervious Area (acres)	GI Solutions Impervious Area (acres)		
			Low Implementation	Medium Implementation	High Implementation
101	285.6	147.2	132.5	103.0	73.7
102	74.9	41.3	37.2	28.9	20.7
103	84.0	42.1	37.9	29.5	21.1

TABLE 4-7
Green Infrastructure Solutions Summary
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Existing Drainage Area (acres)	Existing Impervious Area (acres)	GI Solutions Impervious Area (acres)		
			Low Implementation	Medium Implementation	High Implementation
104	57.7	25.8	23.3	18.1	12.9
105	38.2	18.3	16.5	12.8	9.2
106	22.8	11.2	10.1	7.9	5.6
107	160.7	69.2	62.3	48.5	34.7
108	1.2	0.5	0.5	0.4	0.3
109	114.5	40.5	36.4	28.3	20.3
110	60.8	20.4	18.4	14.3	10.2
111	31.4	11.7	10.5	8.2	5.8
112	38.6	11.7	10.5	8.2	5.8
113	21.4	7.9	7.1	5.5	4.0
114	20.0	12.9	11.6	9.0	6.4
115	19.5	13.5	12.2	9.5	6.8
116	134.9	63.8	57.4	44.6	31.9
117	12.8	7.0	6.3	4.9	3.5
118	12.2	5.6	5.1	4.0	2.8
119	26.7	16.5	14.9	11.6	14.9
120	35.4	21.0	18.9	14.7	18.9
121	13.3	6.0	5.4	4.2	5.4
122	8.7	3.2	2.9	2.2	2.9
123	24.8	14.1	12.7	9.9	12.7

Maps of the results of the low, medium, and high GI solutions are provided on Figures 4-6 through 4-8, and a summary of the model results is provided in Table 4-8.

FIGURE 4-5
Green Infrastructure Drainage Areas and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

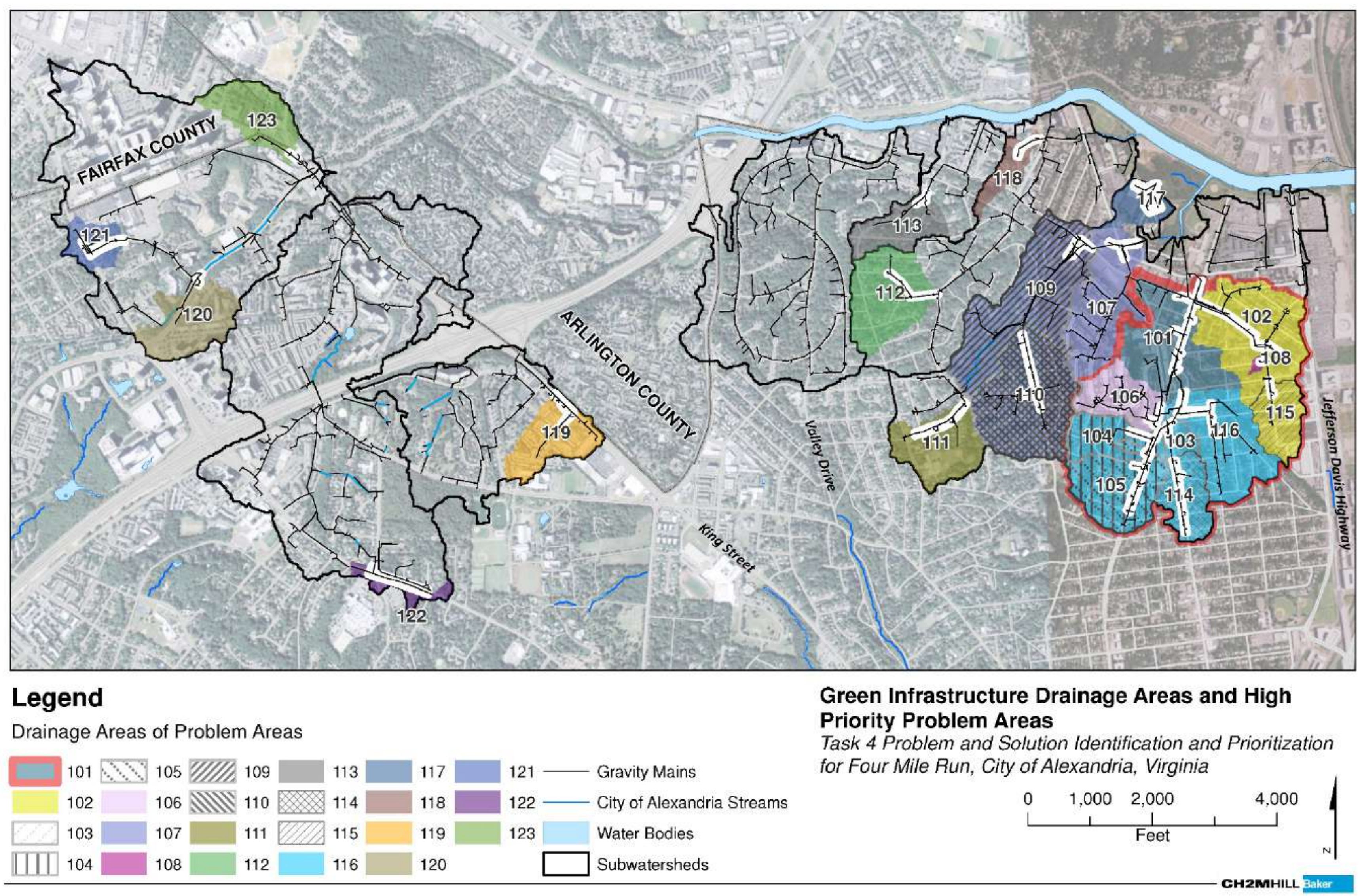


FIGURE 4-6
Low Implementation Green Infrastructure Solutions Model Results and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

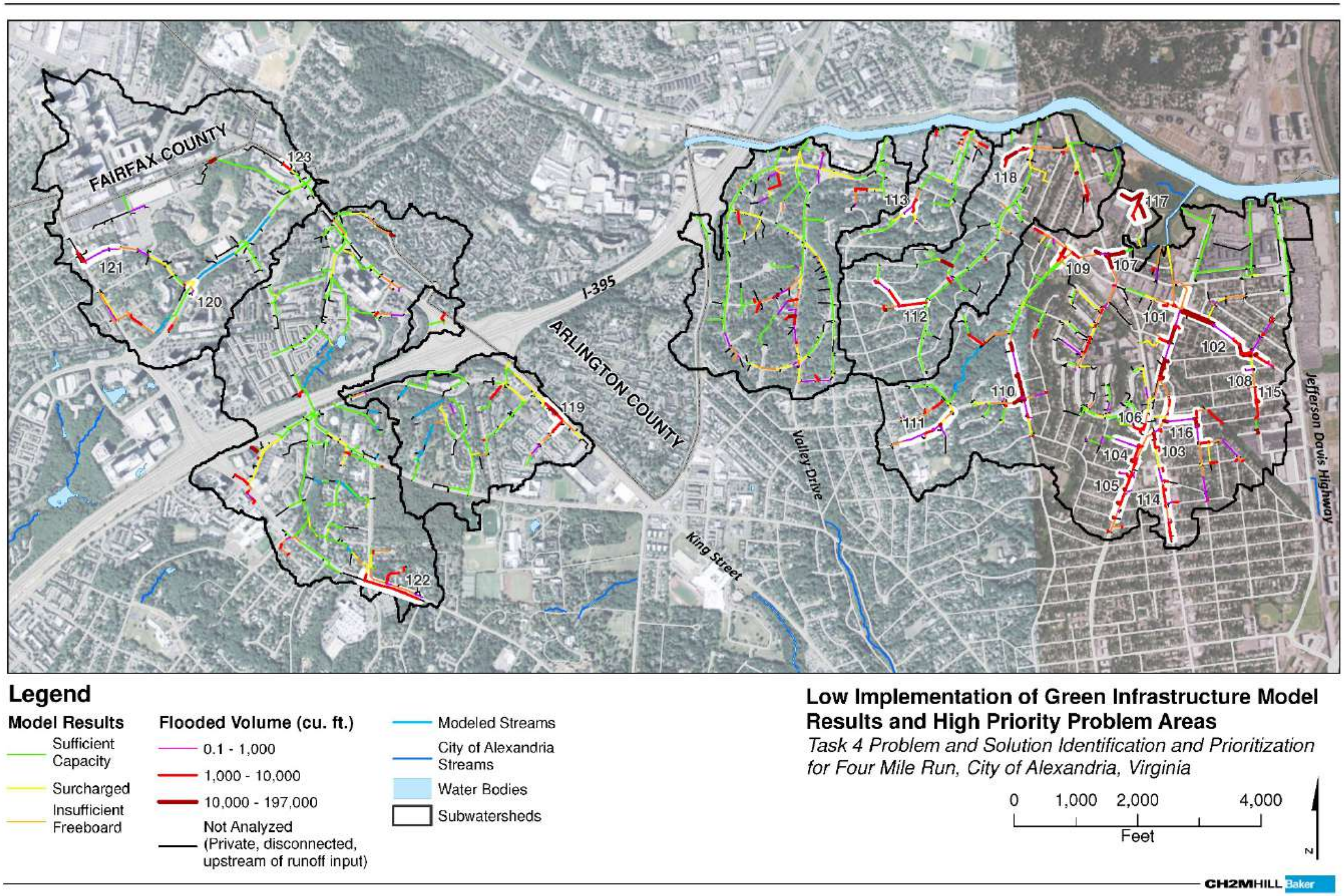


FIGURE 4-7
Medium Implementation Green Infrastructure Solutions Model Results and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

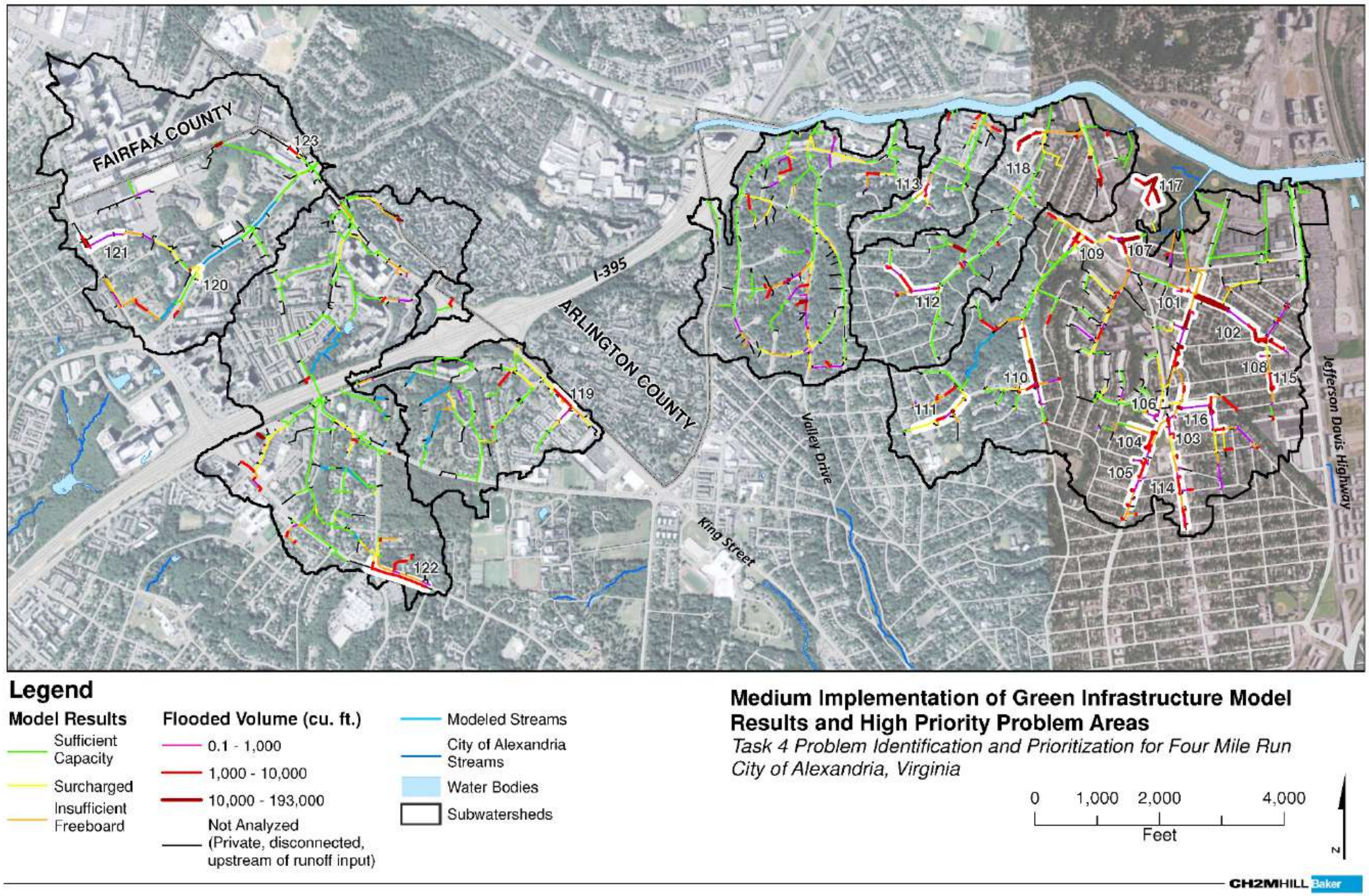


FIGURE 4-8
High Implementation Green Infrastructure Solutions Model Results and High Priority Problem Areas
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

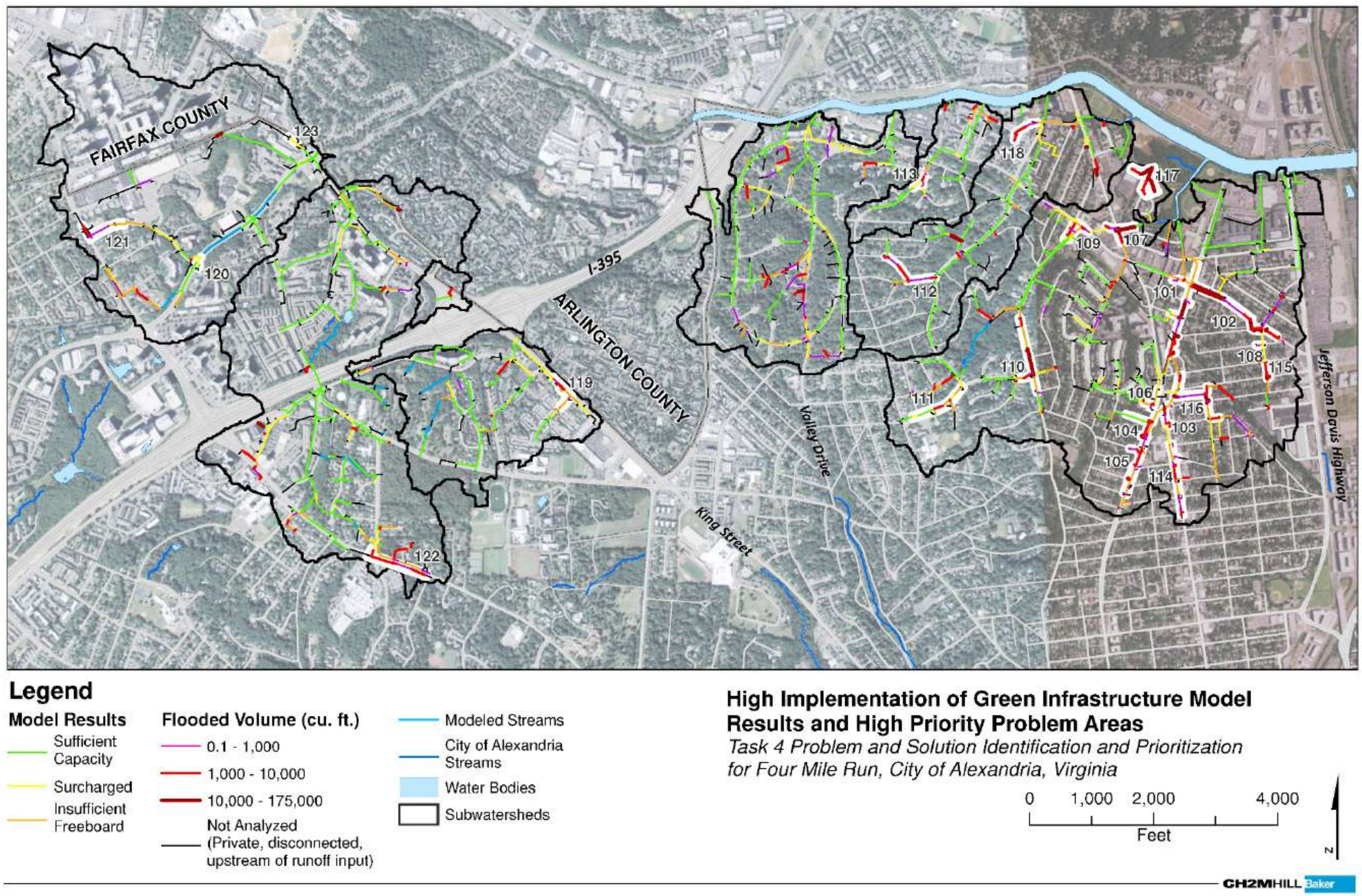


TABLE 4-8
Summary of Existing Conditions Model and Green Infrastructure Solutions Model Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

	Existing Conditions Results				Low GI Implementation Results				Medium GI Implementation Results				High GI Implementation Results			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Durati on (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	72,570	46	-	-	74,959	47	-	-	77,191	49	-	-	80,532	51	-	-
Surcharged[a]	22,216	14	2.262	-	22,167	14	1,514	-	23,326	15	1,448	-	22,667	14	1,386	-
Insufficient Freeboard	25,337	16	-	-	26,341	17	-	-	26,102	16	-	-	27,582	17	-	-
Flooded	38,634	24	746	3,257,585	35,289	22	680	2,632,705	32,137	20	638	2,328,215	27,974	18	592	1,994,021

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits are surcharged, have insufficient freeboard, or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

Overall, model results indicate that GI is effective at reducing flood volumes and durations. On the low end, a 10 percent impervious reduction by low GI implementation reduces length of flooding in the network by about 2 percent and reduces the overall flood volume by about 19 percent. The duration of flooding is also reduced slightly compared to the existing conditions results. At the high end, a 50 percent reduction in impervious area reduces length of flooding in the network by about 6 percent and reduces flood volume by about 39 percent.

Flooding outside of the high-priority problem areas was not addressed by the proposed solutions, therefore, results within each high-priority problem area are shown in Tables 4-9 and 4-10. On average, the flood volume was reduced by 18 percent in high-priority problem areas by low GI implementation, 36 percent by the medium GI implementation, and about 54 percent by the high GI implementation. Peak flow results were less dramatic, with the low GI implementation reducing peak flow by about 7 percent on average, medium GI implementation reducing peak flow by about 9 percent, and high GI implementation reducing peak flow by 11 percent.

TABLE 4-9
Green Infrastructure Solutions Flood Volume Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Existing Conditions Flood Volume (MG)	Low GI Implementation		Medium GI Implementation		High GI Implementation	
		Solution Flood Volume (MG)	Percent Reduction	Solution Flood Volume (MG)	Percent Reduction	Solution Flood Volume (MG)	Percent Reduction
101	3.542	1.382	61	1.182	67	0.973	73
102	2.168	1.817	16	1.506	31	1.315	39
103	0.347	0.327	6	0.287	17	0.238	31
104	0.448	0.424	6	0.376	16	0.327	27
105	0.653	0.600	8	0.485	26	0.363	44
106	0.130	0.083	36	0.048	63	0.020	85
107	3.655	3.497	4	3.380	8	3.059	16
108	0.010	0.007	30	0.004	54	0.001	85
109	0.288	0.234	19	0.234	19	0.138	52
110	1.284	1.221	5	1.097	15	0.958	25
111	0.279	0.233	17	0.149	46	0.084	70
112	0.193	0.180	7	0.154	20	0.127	34
113	0.129	0.110	15	0.076	41	0.042	67
114	0.315	0.280	11	0.198	37	0.118	63
115	0.342	0.325	5	0.266	22	0.187	45
116	1.160	1.061	9	0.936	19	0.795	31
117	1.335	1.261	6	1.106	17	0.963	28
118	0.417	0.380	9	0.310	26	0.238	43
119	0.242	0.202	17	0.126	48	0.036	85
120	0.005	0.001	88	-	100	-	100
121	0.070	0.060	14	0.042	40	0.027	62
122	0.142	0.130	8	0.106	26	0.081	43
123	0.099	0.072	27	0.025	74	-	100
		Average	**18**	**Average**	**36**	**Average**	**54**

TABLE 4-10
Green Infrastructure Solutions Peak Flow Model Results by Problem Area
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Existing Conditions Peak Flow (cfs)	Low GI Implementation		Medium GI Implementation		High GI Implementation	
		Solution Peak Flow (cfs)	Percent Reduction[a]	Solution Peak Flow (cfs)	Percent Reduction[a]	Solution Peak Flow (cfs)	Percent Reduction[a]
101	107.8	95.8	11	94.8	12	93.6	13
102	219.0	121.4	45	115.1	47	112.5	49
103	104.0	103.7	0.3	103.1	0.9	102.6	1
104	66.2	65.9	0.5	65.3	1	64.9	2
105	53.4	53.3	0.2	53.5	-0.1	53.5	-0.1
106	78.3	76.4	2	75.7	3	74.9	4
107	297.6	297.1	0.2	296.8	0.3	295.2	0.8
108	46.8	46.8	0.1	46.6	0.4	46.3	1
109	362.5	362.2	0.1	362.1	0.1	361.6	0.2
110	83.6	83.4	0.3	83.0	0.7	82.5	1
111	62.4	61.9	0.8	60.9	2	59.7	4
112	150.4	150.3	0.1	149.9	0.3	149.6	0.5
113	60.4	60.2	0.3	59.7	1	58.3	3
114	38.6	38.4	0.4	38.1	1	37.6	2
115	33.5	33.1	1	32.9	2	32.5	3
116	138.2	138.4	-0.1	137.2	0.7	135.5	2
117	10.0	9.7	3	9.5	5	9.2	8
118	15.4	15.5	-0.8	14.4	7	12.6	19
119	75.3	75.0	0.5	74.1	2	73.1	3
120	185.4	183.3	1	171.6	7	158.5	15
121	32.2	31.8	1	30.5	5	29.1	10
122	13.4	13.3	0.4	13.2	1	13.1	2
123	65.3	64.9	0.6	64.0	2	60.0	8
		Average	**3.0**		**4.5**		**6.7**

Notes:
[a] Negative value in Percent Reduction column indicates increase in peak flow

SECTION 5

Alternatives Analysis and Prioritization

The alternatives analysis and prioritization goal was to evaluate the cost and performance of the various solution approaches and technologies and develop watershed-wide alternatives aimed at resolving capacity-related problems in the Four Mile Run watershed. The solution identification process resulted in 109 unique projects for the 23 high-priority problem areas. The alternatives analysis and prioritization was performed after completing the solution modeling for the high-priority problem areas. The following section describes the results of the alternatives analysis and prioritization.

5.1 Problem Area Benefit Analysis

The 109 solutions for the 23 high-priority problem areas were scored for the eight solution evaluation criteria:

- Urban drainage and flooding
- Environmental compliance
- EcoCity goals and sustainability
- Social benefits
- Integrated asset management
- City-wide maintenance implications
- Constructability
- Public acceptability

After completing preliminary scoring of projects in Hooffs Run, City staff reviewed prioritization results to ensure the objectives of the analysis were being met. This review resulted in a minimum flood reduction threshold of 22 percent for all projects. If projects did not meet this minimum threshold, they were not included in the prioritization, though the scoring and costing data were maintained for documentation. Of the 109 solutions, 36 did not meet the minimum flood reduction threshold, leaving 73 projects.

Figures 5-1 through 5-3 show bar charts of the total benefit scores for each of these 73 projects. The horizontal axis has the project name, which is a combination of the problem area number and the technology and solution approach type. For example, CONV-101 is the conveyance solution for problem area 101; STOR-1 is the storage solution; and LGI-101, MGI-101, and HGI-101 are the low, medium, and high GI implementations, respectively. The charts show all solutions included in the prioritization (that is, all solutions providing at least 22 percent reduction in flooding) by problem area in ascending order from left to right.

A full table of the scoring and alternatives analysis results is included in Appendix D.

FIGURE 5-1
Total Benefit Score Chart for High Priority Problem Areas 101 through 108
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

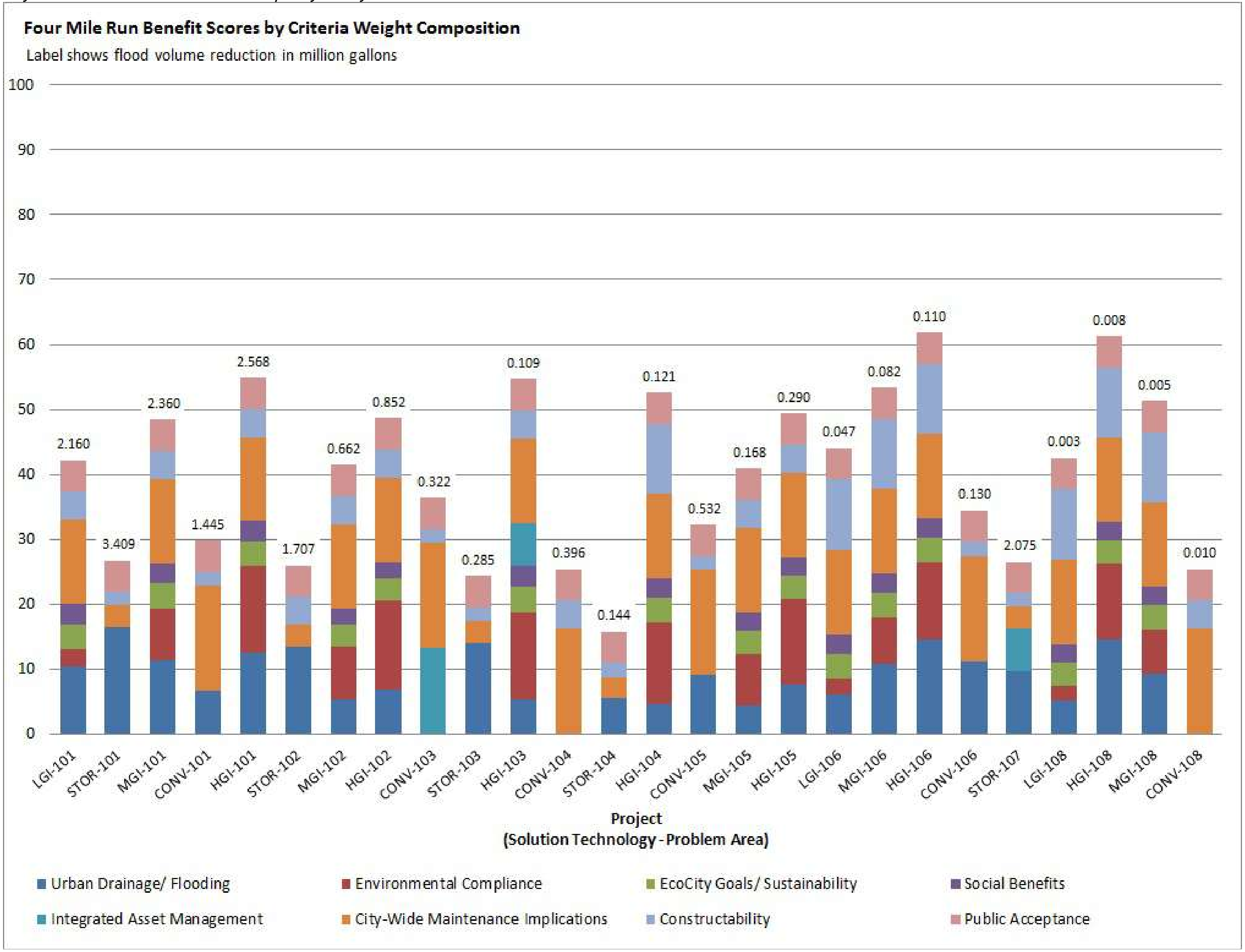


FIGURE 5-2
Total Benefit Score Chart for High Priority Problem Areas 109 through 116
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

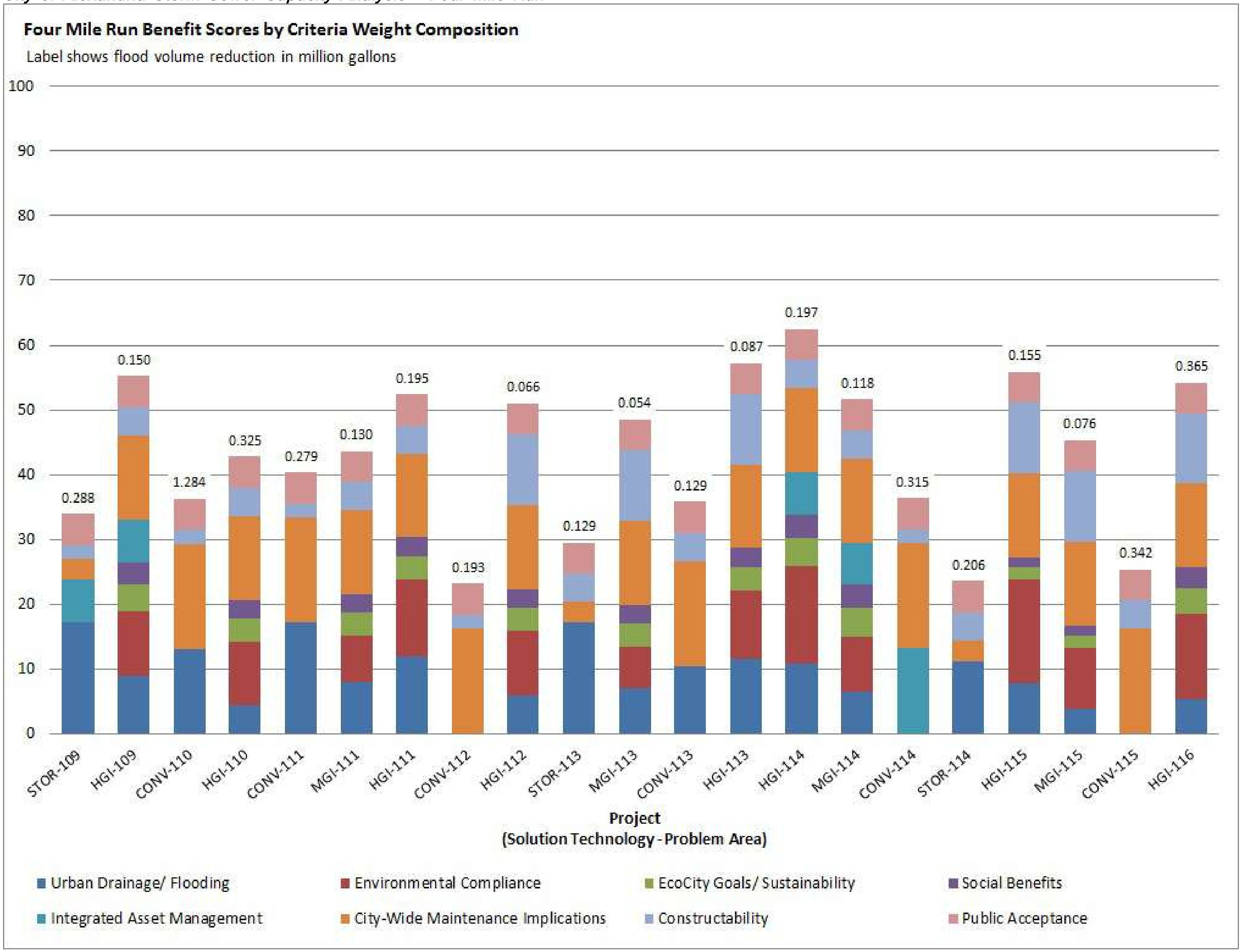
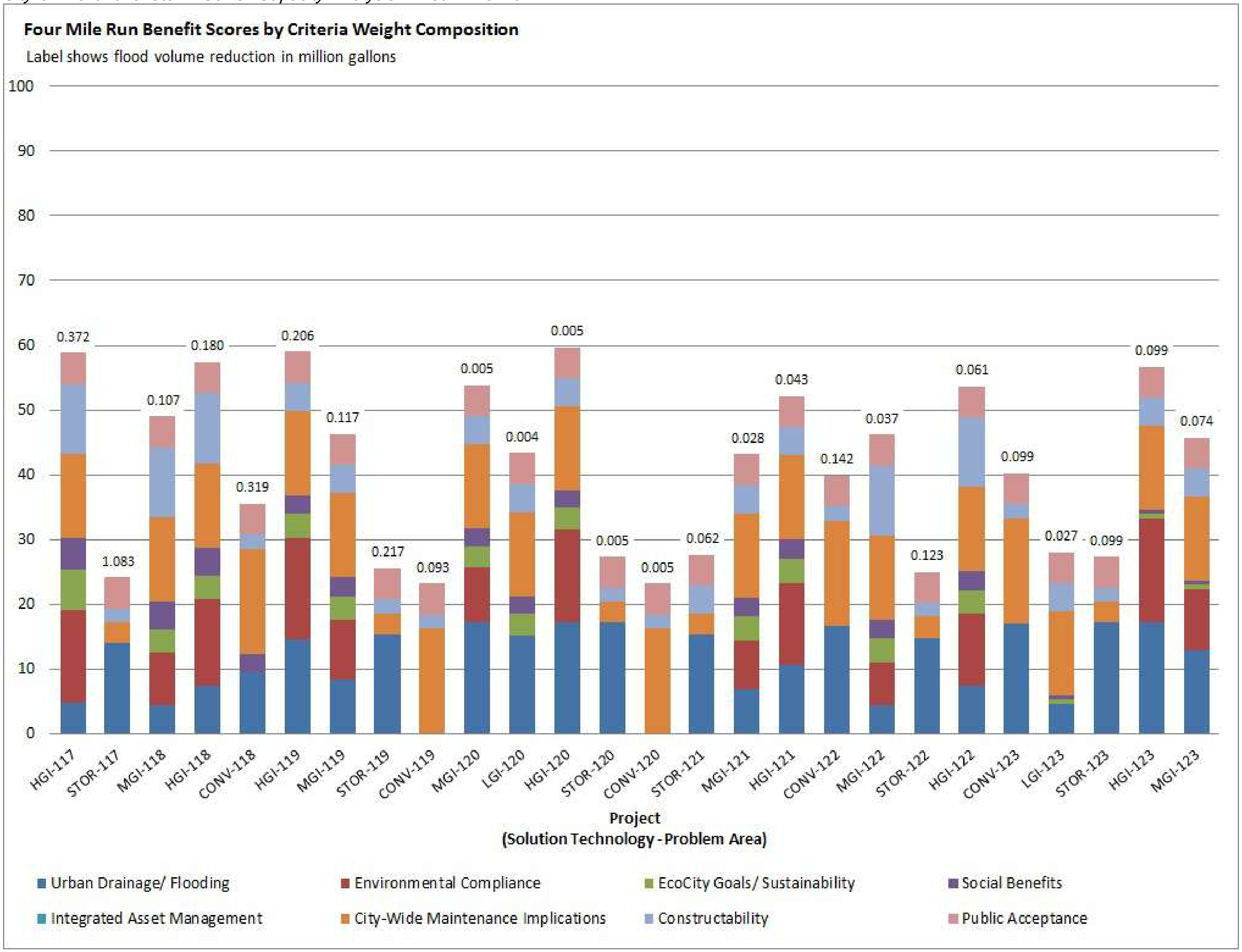


FIGURE 5-3
Total Benefit Score Chart for High Priority Problem Areas 117 through 123
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



5.2 Problem Area Solution Costs

Planning-level capital costs (including construction, engineering, design, and contingency), were developed for each of the 109 solutions. The basis of the costs information for each technology is provided in Appendix E. The basic unit costs used for costing the various projects were the same across all City infrastructure projects. Three levels of GI implementation were evaluated for this project:

- High Implementation – Manage 50 percent of total impervious area in the watershed
- Medium Implementation – Manage 30 percent of total impervious area in the watershed
- Low Implementation – Manage 10 percent of total impervious area in the watershed

The unit cost of implementing GI at the various implementation levels is driven by the availability of GI opportunity areas. Since the GI opportunity areas varied across watersheds, the cost of implementation of the various levels of GI also varies across watersheds. Table 5-1 provides the construction cost assumptions for low, medium, and high implementation levels of GI in the Four Mile Run watershed based on implementing GI across the whole watershed.

TABLE 5-1
Green Infrastructure Construction Costs
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

GI Level	Area Managed		Cost Per Acre Managed	Construction Cost
	%	Acres		
LGI	10	94.0	$49,009	$4,604,896
MGI	30	281.9	$81,572	$22,993,617
HGI	50	469.8	$124,811	$58,636,154

Table 5-2 provides the capital cost in millions of dollars for all 109 solutions. Projects that do not meet the minimum threshold for flood reduction are shown in ***bold italics***.

TABLE 5-2
Capital Costs for High Priority Problem Area Solutions
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area	Conveyance	Storage	Low GI	Medium GI	High GI
101	$3.91	$3.79	$1.11	$5.52	$14.09
102	***$2.60***	$2.36	***$0.38***	$1.90	$4.84
103	$0.92	$0.87	***$0.29***	***$1.44***	$3.67
104	$0.59	$1.89	***$0.18***	***$0.89***	$2.26
105	$0.87	N/A	***$0.13***	$0.63	$1.60
106	$0.37	N/A	$0.08	$0.38	$0.98
107	***$0.80***	$2.66	***$0.48***	***$2.42***	***$6.17***
108	$0.18	N/A	$0.004	$0.02	$0.04
109	***$1.01***	$0.77	***$0.29***	***$1.43***	$3.65
110	$1.38	***$0.24***	***$0.14***	***$0.70***	$1.78
111	$0.63	***$0.07***	***$0.08***	$0.40	$1.02

TABLE 5-2
Capital Costs for High Priority Problem Area Solutions
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area	Conveyance	Storage	Low GI	Medium GI	High GI
112	$0.51	N/A	***$0.08***	***$0.40***	$1.02
113	$0.23	$0.37	***$0.15***	$0.73	$1.87
114	$0.76	$0.30	***$0.09***	$0.44	$1.13
115	$0.25	N/A	***$0.09***	$0.46	$1.18
116	***$1.57***	N/A	***$0.44***	***$2.19***	$5.57
117	***$0.30***	$0.78	***$0.05***	***$0.24***	$0.61
118	$0.36	***$0.15***	***$0.04***	$0.19	$0.49
119	$0.54	$0.89	***$0.11***	$0.57	$1.45
120	$0.27	$1.08	***$0.14***	$0.70	$1.78
121	***$0.41***	$0.45	***$0.04***	$0.21	$0.53
122	$0.58	$0.23	***$0.02***	$0.11	$0.28
123	$0.22	$0.41	***$0.11***	$0.56	$1.43

Notes:
Costs shown in ***bold italics*** are for projects that do not meet the 22 percent minimum flood reduction threshold set by the City.
Costs are in millions of dollars.

5.3 Problem Area Benefit and Cost Results

The benefit/cost score is the ratio of the total benefit divided by the total capital cost in millions of dollars. This metric indicates the cost efficiency of a project and can help direct resources to the projects that will provide the greatest benefit for the lowest cost. Benefit/cost results are presented in Figures 5-4 through 5-7. The charts show only projects meeting the 22 percent minimum flood reduction threshold and are presented by problem area in ascending order from left to right on the horizontal access.

The benefit/cost score is shown as a bar chart in blue. Additionally, the cost per gallon of flood reduction is included as a line on a logarithmic scale. This metric provides an alternative cost-based method for ranking projects. It is important to remember that the best projects will have a high benefit/cost score but a low cost per gallon of flood reduction.

FIGURE 5-4
Benefit/Cost Chart for High Priority Problem Areas 101 through 107
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

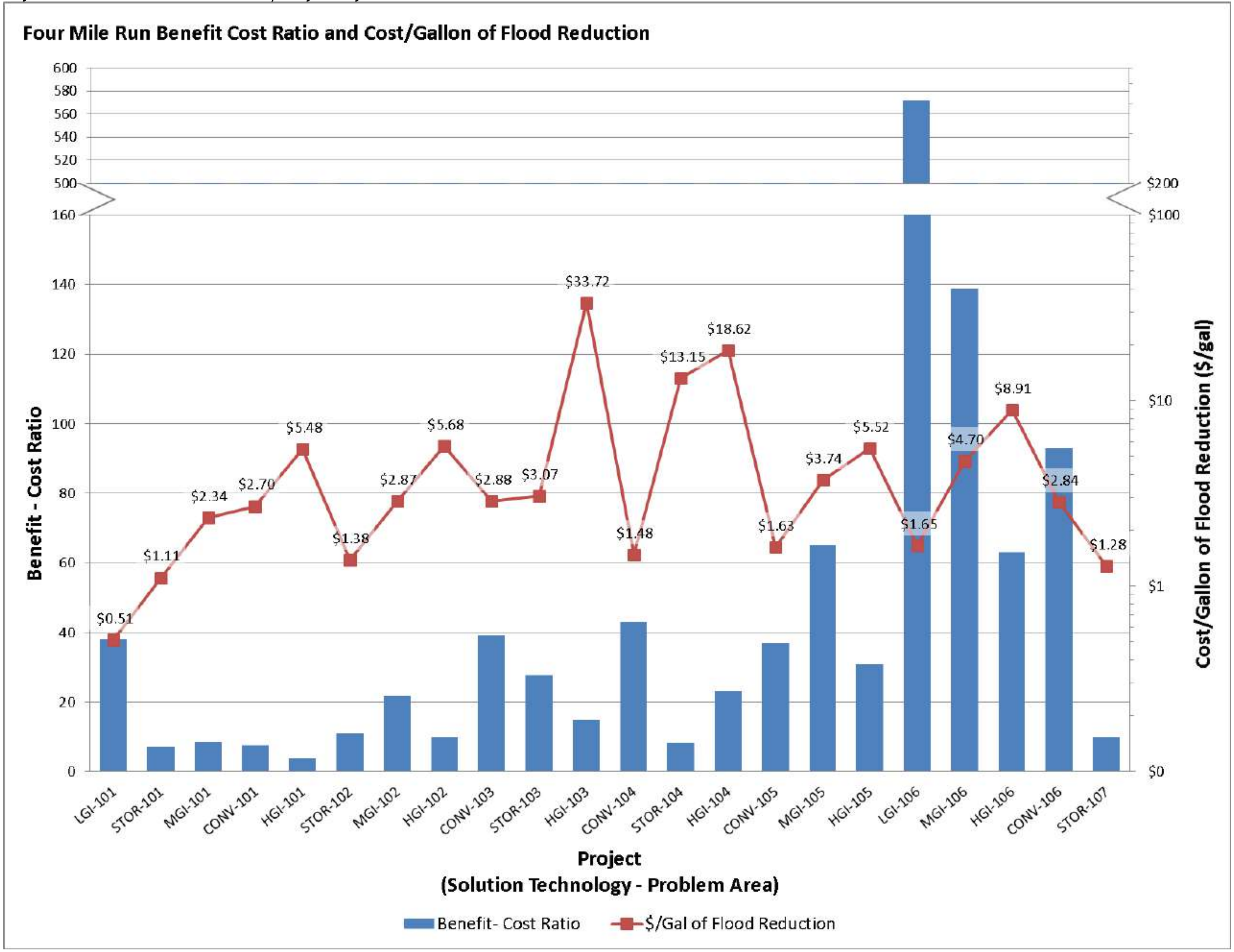


FIGURE 5-5
Benefit/Cost Chart for High Priority Problem Area 108
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

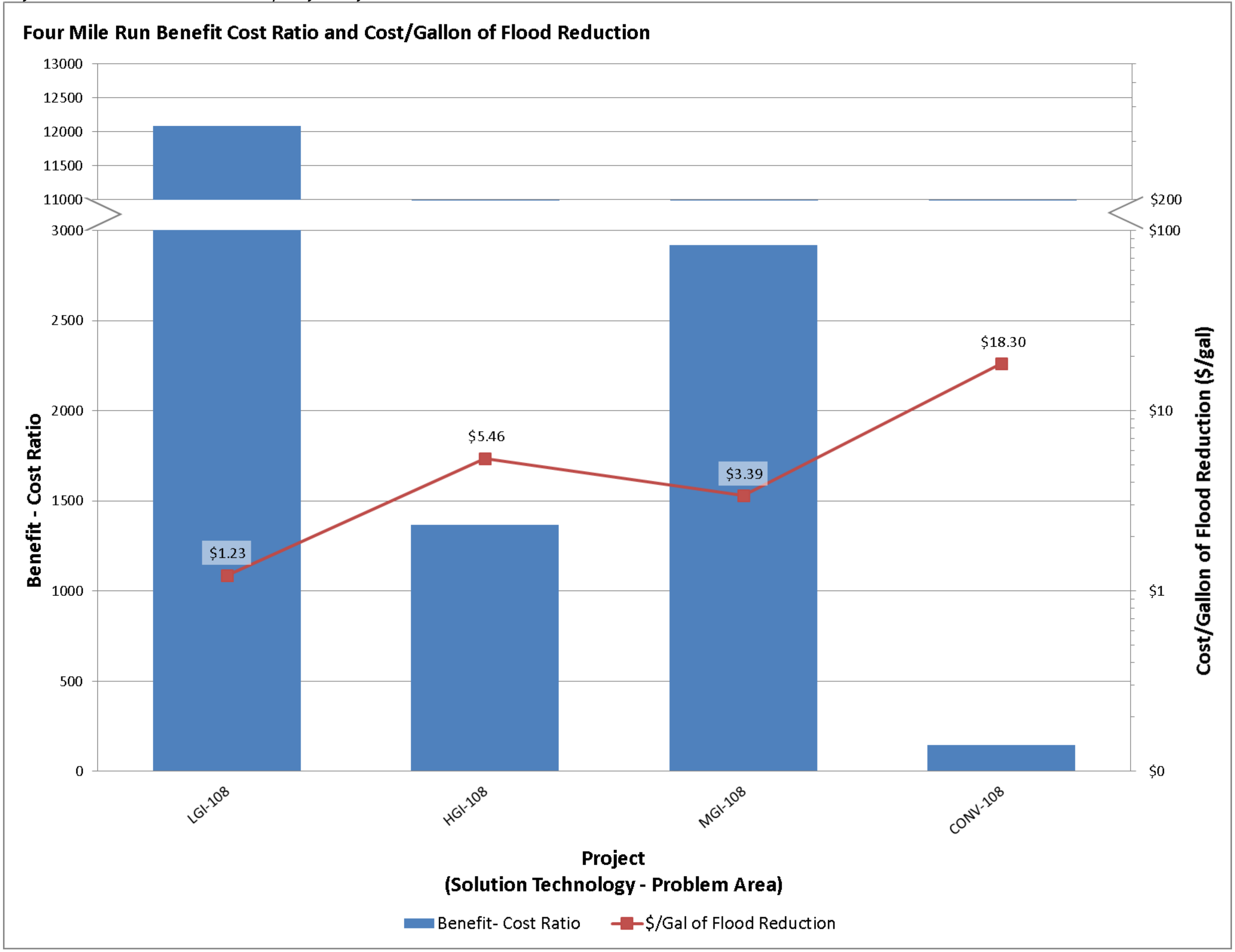


FIGURE 5-6
Benefit/Cost Chart for High Priority Problem Areas 109 through 116
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

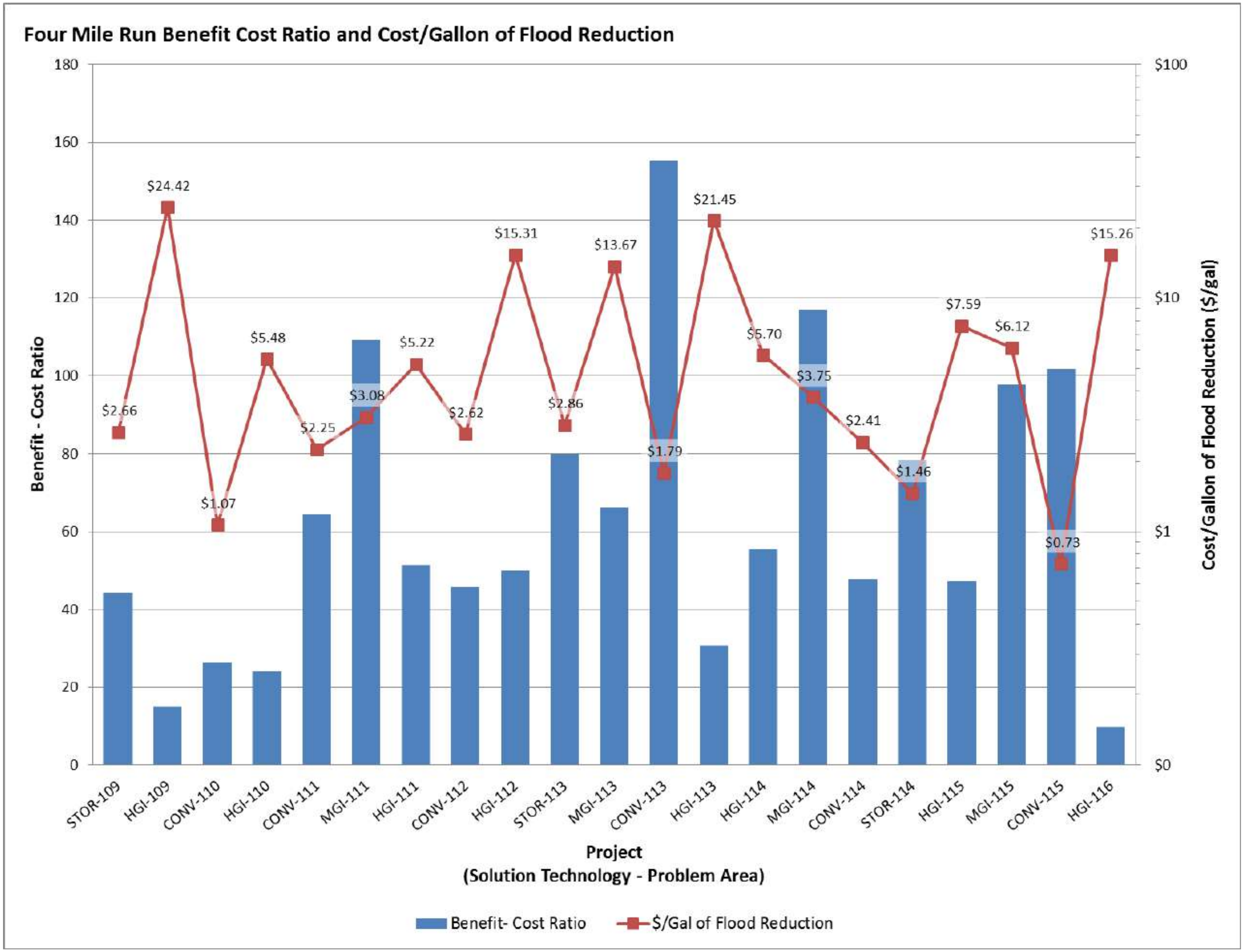
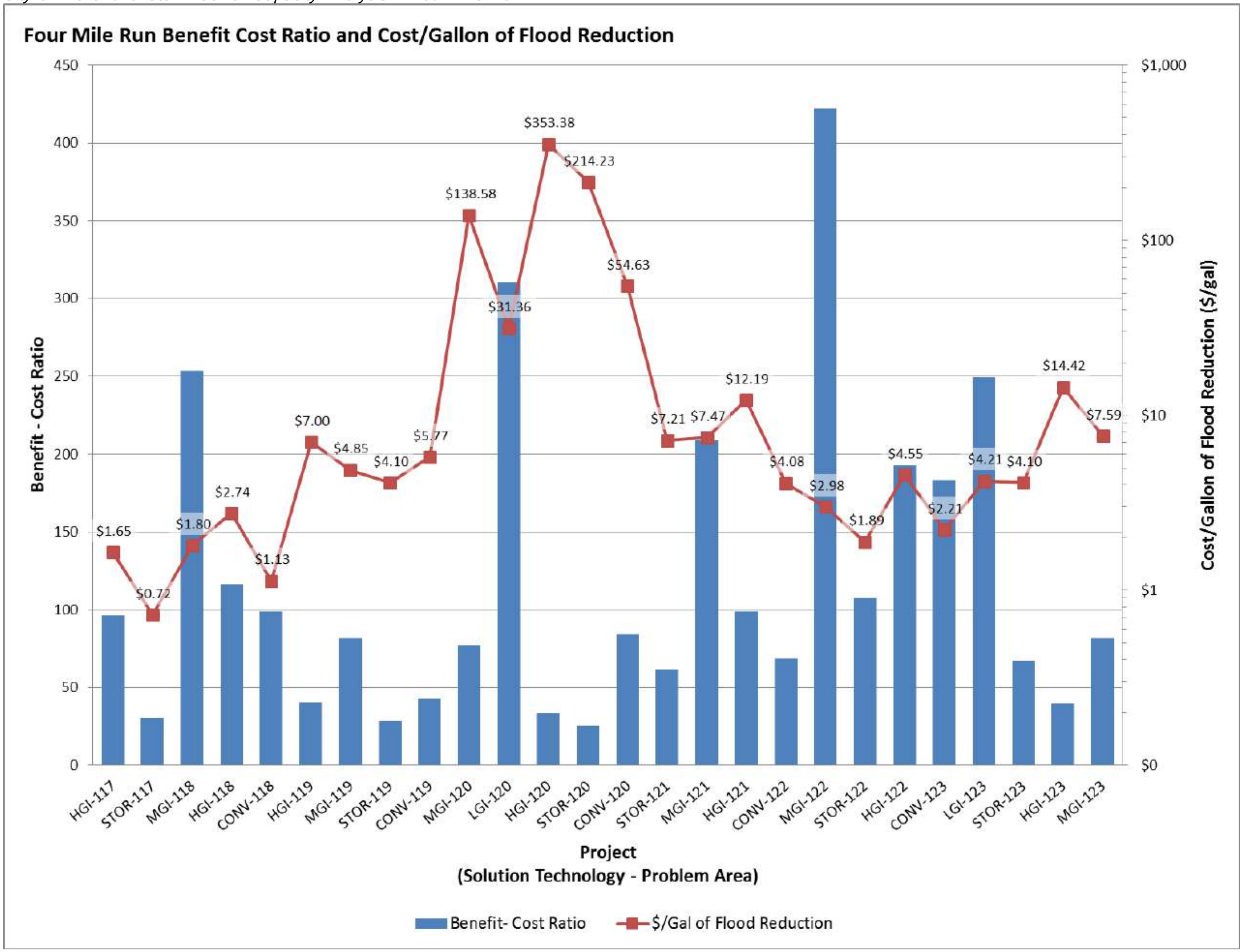


FIGURE 5-7
Benefit/Cost Chart for High Priority Problem Areas 117 through 123
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



5.4 Watershed-wide Alternatives

Three watershed-wide alternatives were developed for Four Mile Run. Each watershed-wide alternative was aimed at resolving capacity-related issues while also meeting a second goal, which includes maximizing cost-efficiency, benefit/cost, or targeting the highest-priority problems. The three alternatives examined include:

- Alternative 1: Most cost-effective solution for each problem area (lowest dollar-per-gallon of flood reduction)
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of best projects to resolve the highest-priority problem areas

Projects were selected for each of the watershed-wide alternatives based on the five individual technology-specific modeling results (Conveyance, Storage, and Low GI, Medium GI, and High GI implementation). A new model including the selected projects was run for each alternative. Results for the watershed-wide model runs are presented in section 5.4.4 and 5.4.5.

5.4.1 Alternative 1: Cost Efficiency

The first alternative focused on providing the best cost efficiency in each problem area. After removing projects that did not meet the minimum flood reduction threshold of 22 percent, the remaining projects were ranked by cost-per-gallon of flood reduction within each problem area in ascending order. The highest-ranked project, which was the project with the lowest $/gallon of flood reduction, was selected for each problem area. Table 5-3 shows the selected project for each problem area. This alternative consisted primarily of conveyance and storage solutions with a few GI projects. Model results are summarized in Table 5-6 and presented on Figure 5-8.

The watershed-wide model results of this alternative show that flooding was not decreased in problem areas 106, 108, and 116 when the 23 projects shown in Table 5-3 were simulated together. Conveyance solutions, while reducing flooding in an upstream problem area, increase peak flow out of the problem area and therefore may increase flows into downstream problem areas. In this alternative, the selected solution for problem areas 106, 108, and 116 are low GI, low GI, and high GI respectively. Because conveyance capacity was not also increased in these problem areas, the increased peak flow experienced at these locations due to upstream conveyance projects caused additional flooding within the problem areas, even while storage and GI solutions were implemented. These downstream impacts are captured in Table 5-7, which summarizes each watershed-wide alternative.

TABLE 5-3
Selected Projects for Watershed-wide Alternative 1: Cost Efficiency
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
101	Low GI	LGI-101	$1.106	38.1	2.160	61	$0.51
102	Storage	STOR-102	$2.357	11.0	1.707	79	$1.38
103	Conveyance	CONV-103	$0.925	39.3	0.322	93	$2.88
104	Conveyance	CONV-104	$0.588	43.2	0.396	88	$1.48
105	Conveyance	CONV-105	$0.868	37.1	0.532	82	$1.63
106	Low GI	LGI-106	$0.077	571.6	0.047	36	$1.65
107	Storage	STOR-107	$2.661	10.0	2.075	57	$1.28
108	Low GI	LGI-108	$0.004	12,089	0.003	30	$1.23
109	Storage	STOR-109	$0.767	44.2	0.288	100	$2.66

TABLE 5-3
Selected Projects for Watershed-wide Alternative 1: Cost Efficiency
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
110	Conveyance	CONV-110	$1.375	26.4	1.284	100	$1.07
111	Conveyance	CONV-111	$0.627	64.3	0.279	100	$2.25
112	Conveyance	CONV-112	$0.506	45.8	0.193	100	$2.62
113	Conveyance	CONV-113	$0.231	155.1	0.129	100	$1.79
114	Storage	STOR-114	$0.301	78.3	0.206	65	$1.46
115	Conveyance	CONV-115	$0.249	101.7	0.342	100	$0.73
116	High GI	HGI-116	$5.573	9.7	0.365	31	$15.26
117	Storage	STOR-117	$0.784	30.8	1.083	81	$0.72
118	Conveyance	CONV-118	$0.360	98.7	0.319	76	$1.13
119	Storage	STOR-119	$0.890	28.7	0.217	89	$4.10
120	Low GI	LGI-120	$0.139	310.7	0.004	88	$31.36
121	Storage	STOR-121	$0.448	61.6	0.062	89	$7.21
122	Storage	STOR-122	$0.233	107.4	0.123	86	$1.89
123	Conveyance	CONV-123	$0.219	183.3	0.099	100	$2.21
		Total	**$21.289**		**12.234**[a]	**71**	**$1.74**

Notes:
Results presented in this table are based on separate technology runs (Conveyance, Storage, and Low, Medium, and High GI)
[a] Existing flood volume for Problem Areas 101 through 123 is 17.25 MG.

5.4.2 Alternative 2: Benefit/Cost

The second alternative focused on providing the best benefit/cost in each problem area. After removing projects that did not meet the minimum flood reduction threshold of 22 percent, the remaining projects were ranked by benefit/cost in descending order within each problem area. The highest-ranked project in each of the 23 problem areas, which was the project with the highest benefit/cost score, was selected. Table 5-4 shows the selected project for each problem area. This alternative consisted primarily of GI projects with a few storage and conveyance projects. Model results are summarized in Table 5-6 and presented on Figure 5-9.

Similar to Alternative 1, problem areas 108 and 116 experienced an increase in flooding after implementing the selected solutions due to their location downstream of other problem areas. Because the green infrastructure solutions were selected based on results generated in a model that included all 23 green infrastructure solutions, the solutions cannot be expected to provide the same flood reduction performance when paired with conveyance solutions in upstream problem areas. These downstream impacts are captured in Table 6-7, which summarizes each watershed-wide alternative.

TABLE 5-4
Selected Projects for Watershed-wide Alternative 2: Benefit/Cost
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
101	Low GI	LGI-101	$1.106	38.1	2.160	61	$0.51
102	Medium GI	MGI-102	$1.896	21.9	0.662	31	$2.87
103	Conveyance	CONV-103	$0.925	39.3	0.322	93	$2.88
104	Conveyance	CONV-104	$0.588	43.2	0.396	88	$1.48
105	Medium GI	MGI-105	$0.627	65.2	0.168	26	$3.74
106	Low GI	LGI-106	$0.077	571.6	0.047	36	$1.65
107	Storage	STOR-107	$2.661	10.0	2.075	57	$1.28
108	Low GI	LGI-108	$0.004	12,087	0.003	30	$1.23
109	Storage	STOR-109	$0.767	44.2	0.288	100	$2.66
110	Conveyance	CONV-110	$1.375	26.4	1.284	100	$1.07
111	Medium GI	MGI-111	$0.400	109.1	0.130	46	$3.08
112	High GI	HGI-112	$1.018	50.0	0.066	34	$15.31
113	Conveyance	CONV-113	$0.231	155.1	0.129	100	$1.79
114	Medium GI	MGI-114	$0.441	117.1	0.118	37	$3.75
115	Conveyance	CONV-115	$0.249	101.7	0.342	100	$0.73
116	High GI	HGI-116	$5.573	9.7	0.365	31	$15.26
117	High GI	HGI-117	$0.612	96.1	0.372	28	$1.65
118	Medium GI	MGI-118	$0.193	253.5	0.107	26	$1.80
119	Medium GI	MGI-119	$0.567	81.6	0.117	48	$4.85
120	Low GI	LGI-120	$0.139	310.7	0.004	88	$31.36
121	Medium GI	MGI-121	$0.207	208.8	0.028	40	$7.47
122	Medium GI	MGI-122	$0.109	422.4	0.037	26	$2.98
123	Low GI	LGI-123	$0.112	249.3	0.027	27	$4.21
		Total	**$19.877**		**9.244**[a]	**54**	**$2.15**

Notes:
Results presented in this table are based on separate technology runs (Conveyance, Storage, and Low, Medium, and High GI)
[a] Existing flood volume for Problem Areas 101 through 123 is 17.25 MG.

5.4.3 Alternative 3: Highest-priority Problems

The third alternative focused on resolving the highest-priority problems by combining multiple solutions within a problem area. The minimum threshold of 22 percent flood reduction was removed because the goal was to eliminate as much flooding as possible from the problem area. In some cases, the combination of a storage or conveyance project that offered substantial flood reduction combined with a GI project could eliminate flooding within a problem area. The best combination of solutions in terms of cost efficiency, benefit/cost, and overall flood reduction were compiled to attempt to resolve the worst problem areas. Because 23 projects were recommended in Alternatives 1 and 2 (one per project area), 23 projects were selected for Alternative 3 to keep all three alternatives relatively consistent in scale. A total of 23 projects were selected for Problem Areas 101 through 119, 121, and 122. These were the problem areas which scored the highest when the problem areas were originally identified. Table 5-5 shows the selected project(s) for each problem area. Model results are summarized in Table 5-6 and presented in Figure 5-10.

Similar to Alternatives 1 and 2, problem area 116 experienced an increase in flooding after implementing the selected solutions due to its location downstream of other problem areas. Because the green infrastructure solutions were selected based on results generated in a model that included all 23 green infrastructure solutions, the solutions cannot be expected to provide the same flood reduction performance when paired with conveyance solutions in upstream problem areas. These downstream impacts are captured in Table 6-7, which summarizes each watershed-wide alternative.

TABLE 5-5
Selected Projects for Watershed-wide Alternative 3: Highest-priority Problems
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

Problem Area ID	Solution Technology	Project Name	Capital Cost ($M)	Benefit-Cost Ratio	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)
101	Storage	STOR-101	$3.791	7.0	3.409	96	$1.11
101	Low GI	LGI-101	$1.106	38.1	2.160	61	$0.51
102	Storage	STOR-102	$2.357	11.0	1.707	79	$1.38
102	Medium GI	MGI-102	$1.896	21.9	0.662	31	$2.87
103	Conveyance	CONV-103	$0.925	39.3	0.322	93	$2.88
104	Conveyance	CONV-104	$0.588	43.2	0.396	88	$1.48
105	Conveyance	CONV-105	$0.868	37.1	0.532	82	$1.63
106	Low GI	LGI-106	$0.077	571.6	0.047	36	$1.65
107	Storage	STOR-107	$2.661	10.0	2.075	57	$1.28
108	Low GI	LGI-108	$0.004	12,089	0.003	30	$1.23
109	Storage	STOR-109	$0.767	44.2	0.288	100	$2.66
110	Conveyance	CONV-110	$1.375	26.4	1.284	100	$1.07
111	Conveyance	CONV-111	$0.627	64.3	0.279	100	$2.25
112	Conveyance	CONV-112	$0.506	45.8	0.193	100	$2.62
113	Storage	STOR-113	$0.369	80.0	0.129	100	$2.86
114	High GI	HGI-114	$1.125	55.5	0.197	63	$5.70
115	High GI	HGI-115	$1.181	47.3	0.155	45	$7.59
116	High GI	HGI-116	$5.573	9.7	0.365	31	$15.26
117	High GI	HGI-117	$0.612	96.1	0.372	28	$1.65
118	Medium GI	MGI-118	$0.193	253.5	0.107	26	$1.80
119	High GI	HGI-119	$1.445	40.8	0.206	85	$7.00
121	Storage	STOR-121	$0.448	61.6	0.062	89	$7.21

TABLE 5-5

122	Conveyance	CONV-122	$0.581	68.7	0.142	100	$4.08
		Total	**$29.076**		**15.093[a]**	**87**	**$1.93**

Notes:

Results presented in this table are based on separate technology runs (Conveyance, Storage, and Low, Medium, and High GI)

[a] Existing flood volume for Problem Areas 101 through 119, 121, and 122 is 17.15 MG.

5.4.4 Modeling Results

Table 5-6 provides a summary of the hydraulic model results for the three watershed-wide alternatives. Alternative 3, which focuses on resolving the highest-priority problems, provides the greatest reduction of flooding in the system in terms of total length of pipe experiencing flooding, minimizes the duration of flooding, and minimizes the total volume of flooding in the system overall. Maps comparing the model results are presented on Figures 5-8 through 5-10.

Each of the alternatives analyzed is still leaving areas with flooding (as shown by red lines on the maps), largely because those areas are outside the boundaries of the “high-priority problem areas”. These areas were not addressed by solutions because they were either flooding at isolated structures, or did not score high based on the problem area scoring criteria.

TABLE 5-6
Summary of Watershed-wide Alternatives Model Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

	Alternative 1 Results Best Cost Efficiency				Alternative 2 Results Best Benefit/Cost Ratio				Alternative 3 Results Highest-priority Problems			
	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]	Conduit Length (LF)	Percent of Total Length (%)	Total Duration (hrs)	Total Volume (ft^3)[b]
Sufficient Capacity	80,060	50	-	-	76,497	48	-	-	80,017	50	-	-
Surcharged[a]	27,993	18	1,023	-	27,661	17	1,368	-	29,308	18	1,251	-
Insufficient Freeboard	25,918	16	-	-	25,525	16	-	-	27,718	17	-	-
Flooded	24,786	16	207	1,596,331	29,074	18	578	2,008,809	21,714	14	493	1,462,928

Notes:
Results presented for pipe segments are based on capacity at upstream end of pipe.
[a] Duration of surcharged flow includes time during which conduits are surcharged, have insufficient freeboard, or are flooded at upstream end only.
[b] Flooded volume includes volume flooded at upstream end of the conduit.

FIGURE 5-8

Alternative 1: Cost-efficiency Model Results

City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

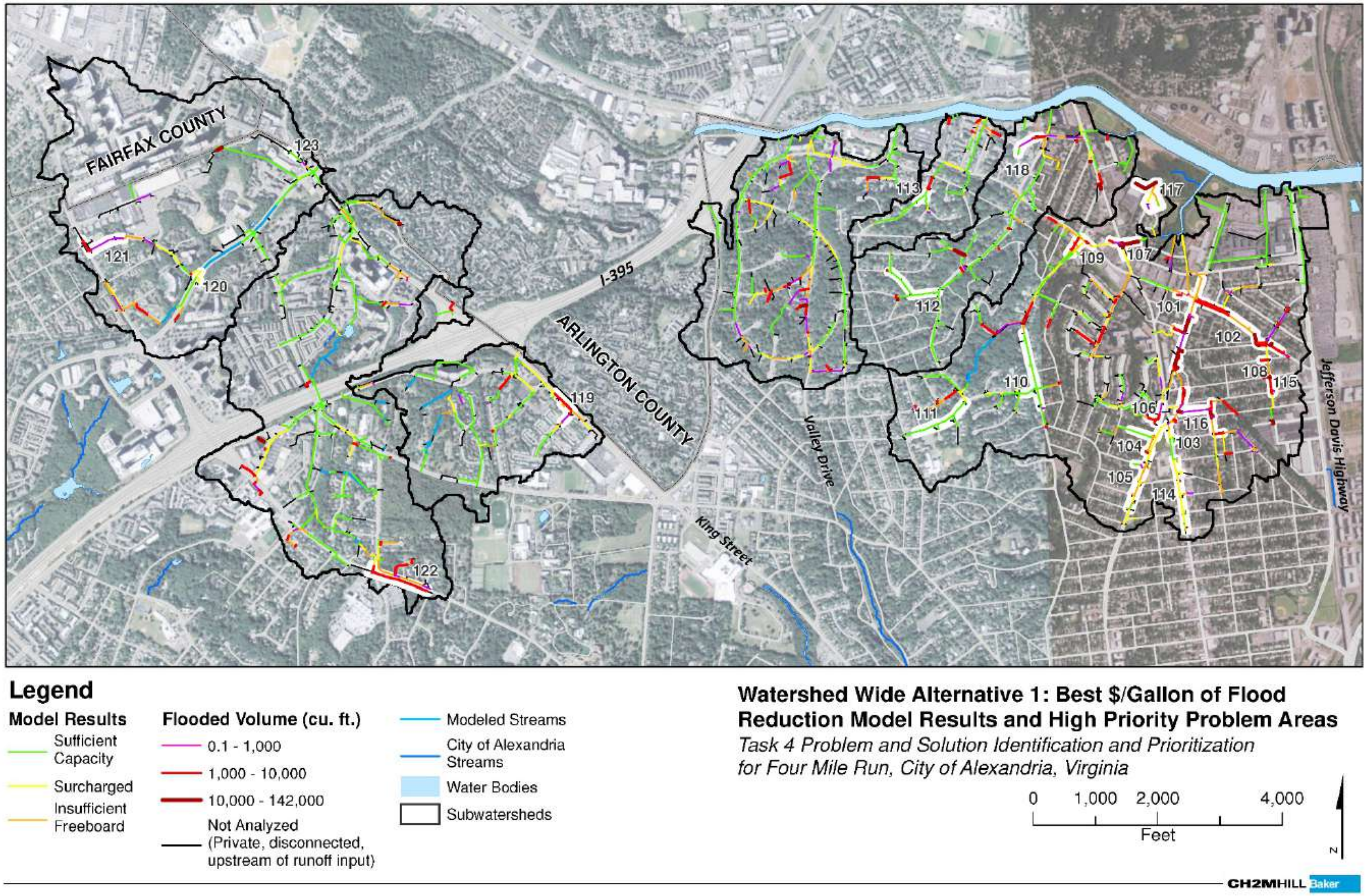


FIGURE 5-9
Alternative 2: Benefit/Cost Model Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

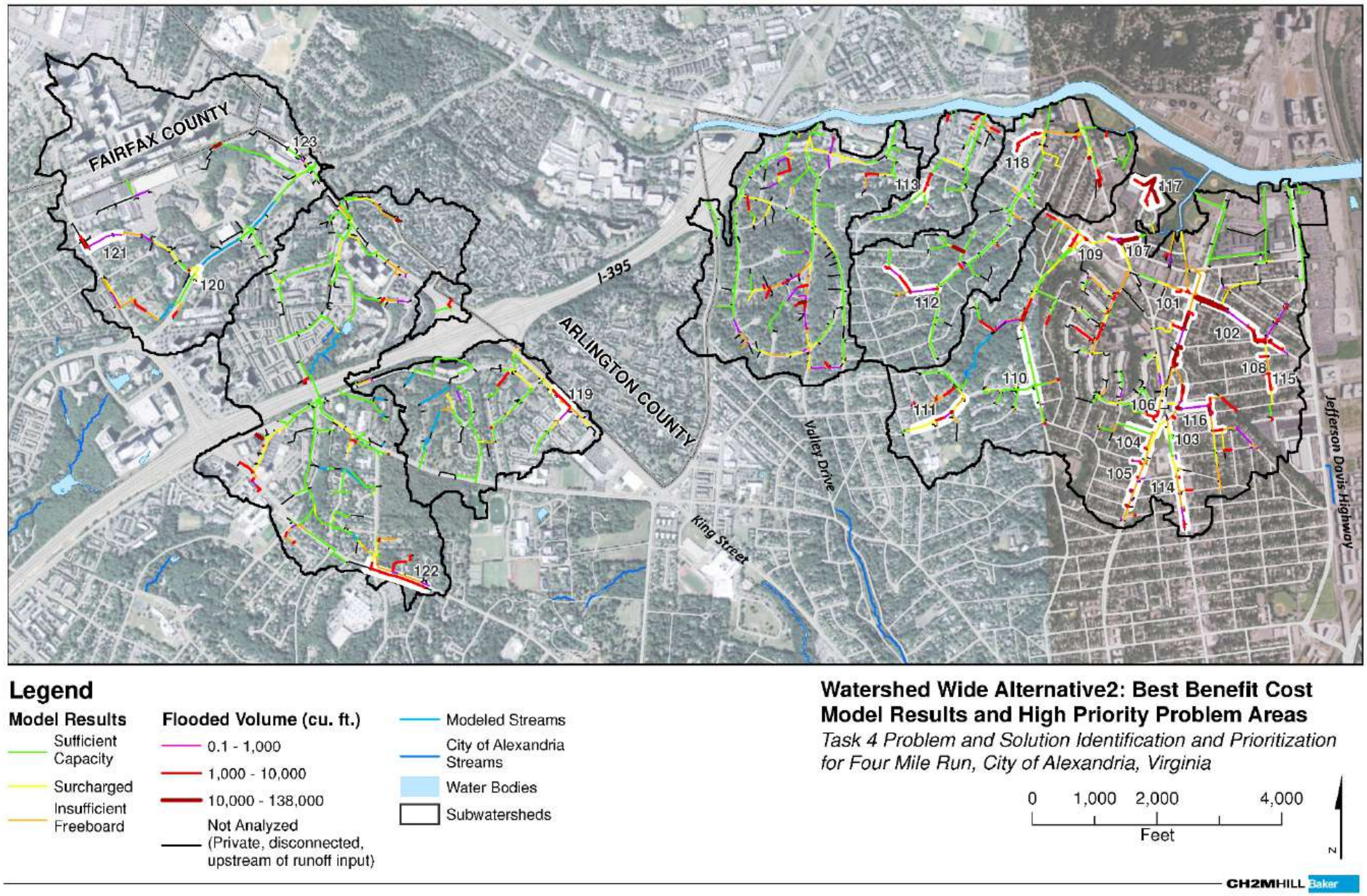
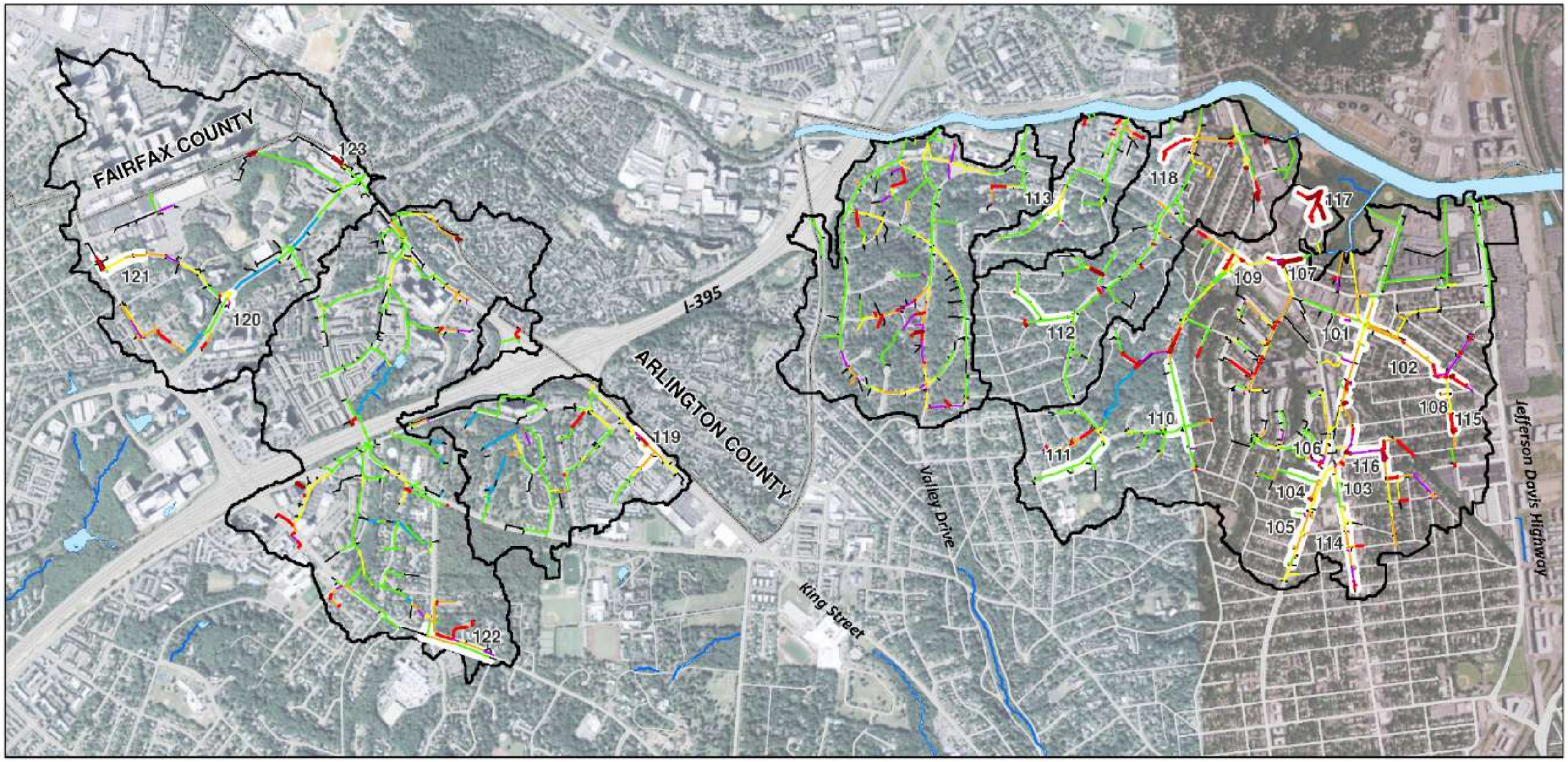


FIGURE 5-10
Alternative 3: Highest-priority Problems Model Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



Legend

Model Results
- Sufficient Capacity
- Surcharged
- Insufficient Freeboard

Flooded Volume (cu. ft.)
- 0.1 - 1,000
- 1,000 - 10,000
- 10,000 - 142,000
- Not Analyzed (Private, disconnected, upstream of runoff input)

- Modeled Streams
- City of Alexandria Streams
- Water Bodies
- Subwatersheds

Watershed Wide Alternative 3: Overall Benefit Score Model Results and High Priority Problem Areas
Task 4 Problem and Solution Identification and Prioritization for Four Mile Run, City of Alexandria, Virginia

0 1,000 2,000 4,000
Feet

N

CH2MHILL Baker

5.4.5 Scoring and Prioritization Results

The results for each alternative generally reflect the objective of that particular alternative. A summary of the results is provided in Table 5-7. A model was run for each of the alternatives, so the alternative-specific results presented in Table 5-7 may differ slightly from the results generated from the technology-specific model runs used to evaluate each solution type.

The watershed-wide results show that all three alternatives provide potential advantages when compared to the others. Alternative 1 has the best cost efficiency in terms of cost of flood reduction, but lowest overall benefit, Alternative 2 provides the greatest cost/benefit, but lowest flood reduction, and Alternative 3 provides the greatest total benefit score, but has the highest capital cost. Since the objective of this study is to provide flood reduction and relieve capacity limitations in the identified problem areas, Alternative 3 is the recommended alternative due to the amount of flood reduction achieved relative to cost and overall benefit. Though this alternative does not have the highest benefit or benefit/cost score of the three watershed-wide alternatives, Alternative 3 provides similar cost efficiency to Alternative 1, but with a higher overall benefit score.

TABLE 5-7
Watershed-wide Alternatives Scoring and Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run

	Alternative 1 - Best Cost Efficiency	Alternative 2 - Best Benefit/Cost Ratio	Alternative 3 – Highest-priority Problems
Total Capital Cost ($ Millions)	$21.7	$19.8	$24.5
Total Benefit Score	754	954	938
Overall Benefit/Cost	34.7	48.2	38.4
Total Flood Reduction (MG)	10.84	7.90	11.53
Cost of Flood Reduction ($/gallon)	$2.00	$2.50	$2.12

Notes:
Results presented in this table are based on watershed-wide alternative models that include the selected projects documented in sections 5.4.1-5.4.3.

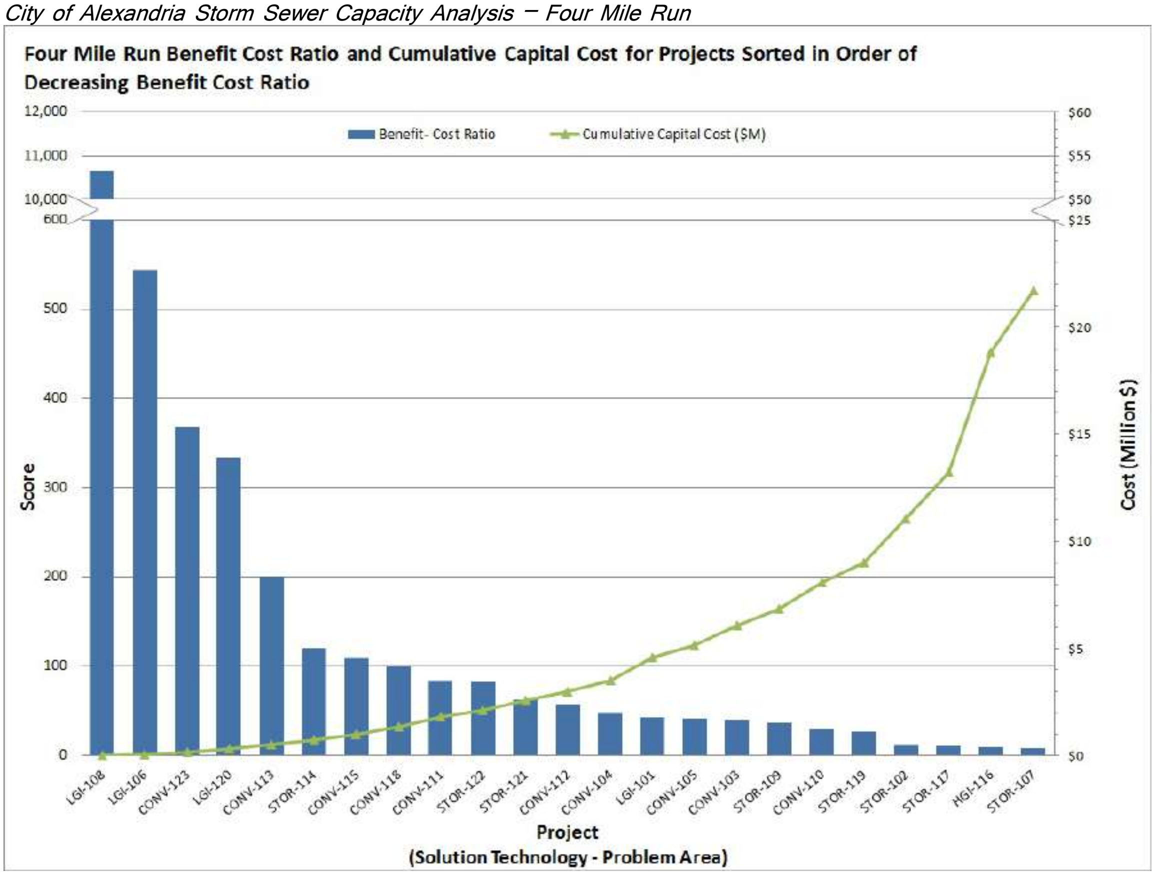
Several problem areas experience a small increase in flooding in all three alternatives. The flood volume increase in these problem areas is reflected in the total flood reduction numbers.

When developing a capital improvement plan, the benefit/cost or cost efficiency ($/gallon of flood reduction) are typically used to guide the order in which projects are implemented. Prioritization results for the three watershed-wide alternatives are presented in Figures 5-11 through 5-13. The top chart shows the benefit/cost ratio and the cumulative capital cost of the alternative. The solutions are provided in order of decreasing benefit/cost ratio; solutions with the greatest benefit/cost ratio are presented on the left and solutions with the lowest benefit/cost ratio are presented on the right.

The bottom chart shows the benefit/cost ratio for each solution in the watershed-wide alternative in order of increasing cost and gallon of flood reduction. In each watershed-wide alternative, there are several projects that have no value for the cost and gallon of flood reduction. These solutions, shown on right side of the chart, are in problem areas that experience an increase in flooding after implementing the selected solutions for the watershed-wide alternative. In each alternative the selection of a conveyance solution upstream and/or downstream of these 3 or 4 problem areas increases peak flow upstream and backwater downstream of these problem areas, which contributes to an increase in flooding elsewhere in the system.

Both charts show the cumulative capital cost plotted on the secondary axis. The solutions on both charts are named by the technology: conveyance (CONV), storage (STOR), LGI, MGI, or HGI, and the problem area number.

FIGURE 5-11
Alternative 1: Best Cost Efficiency Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



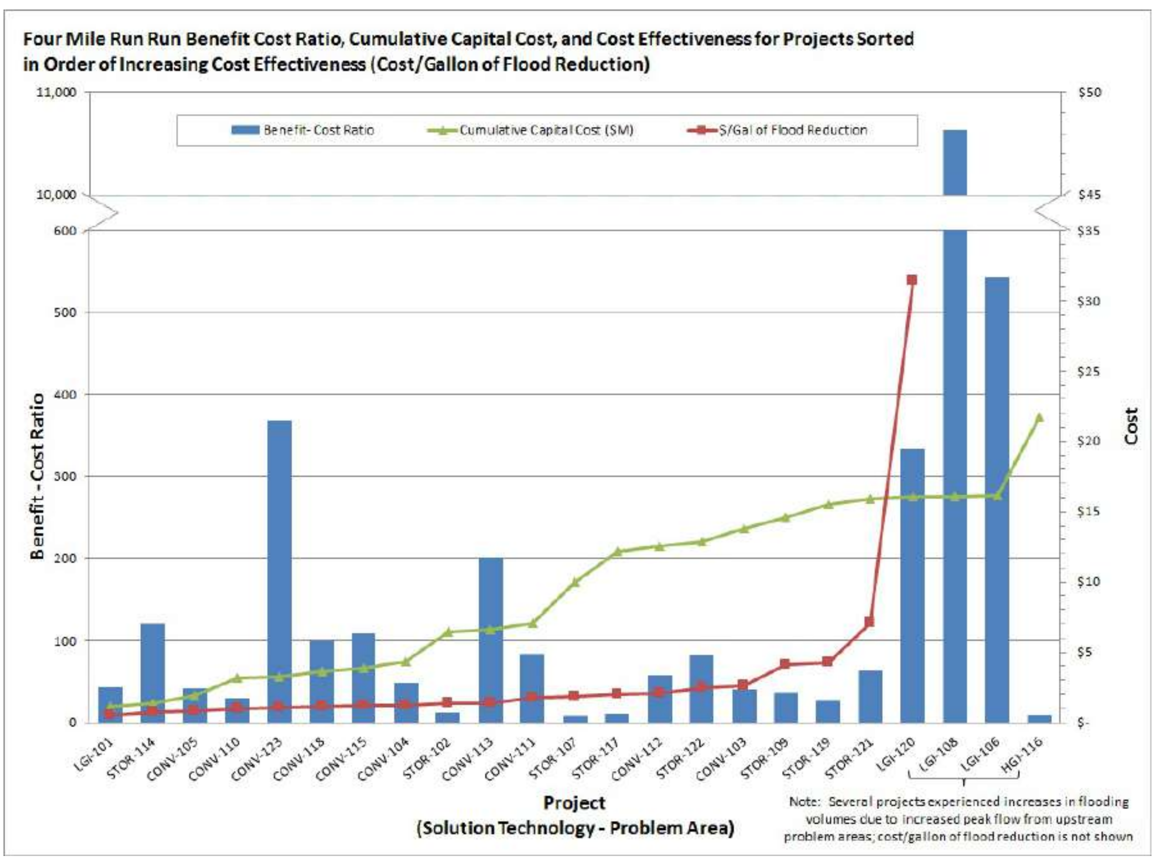
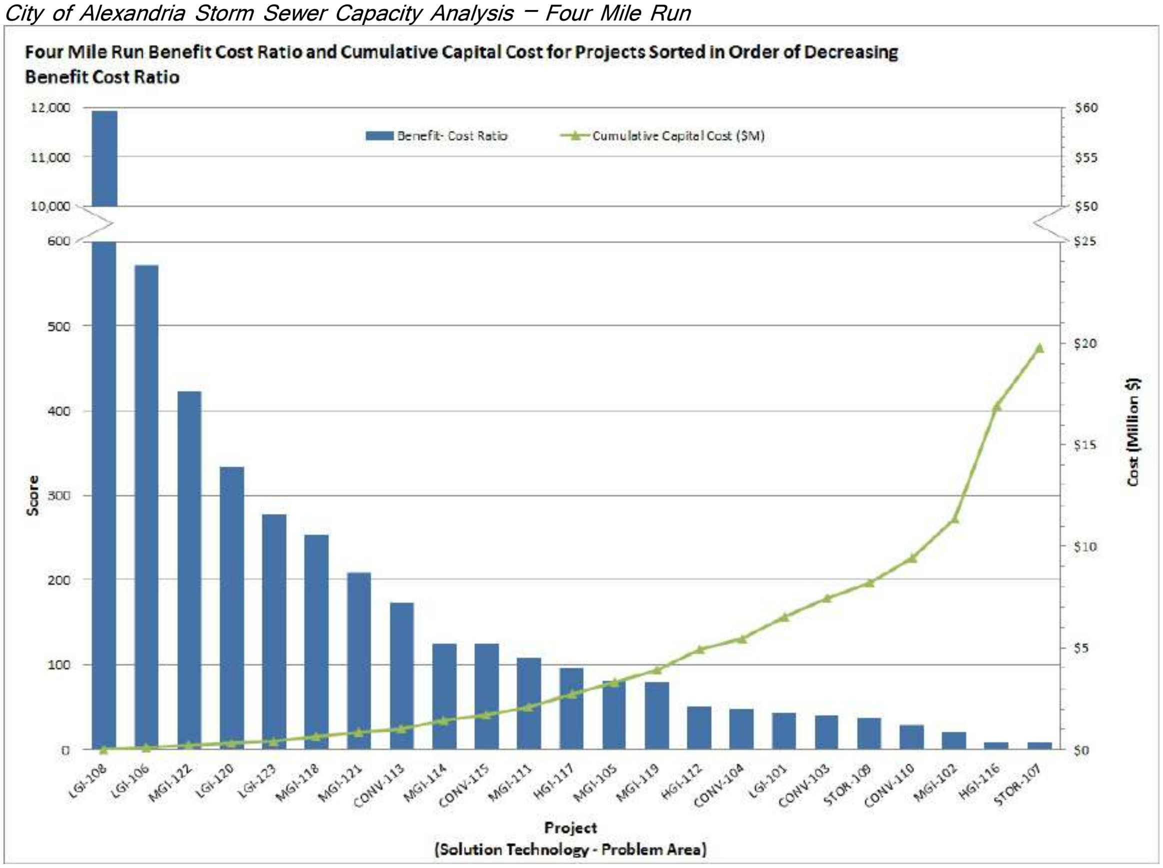


FIGURE 5-12
Alternative 2: Best Benefit/Cost Ratio Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run



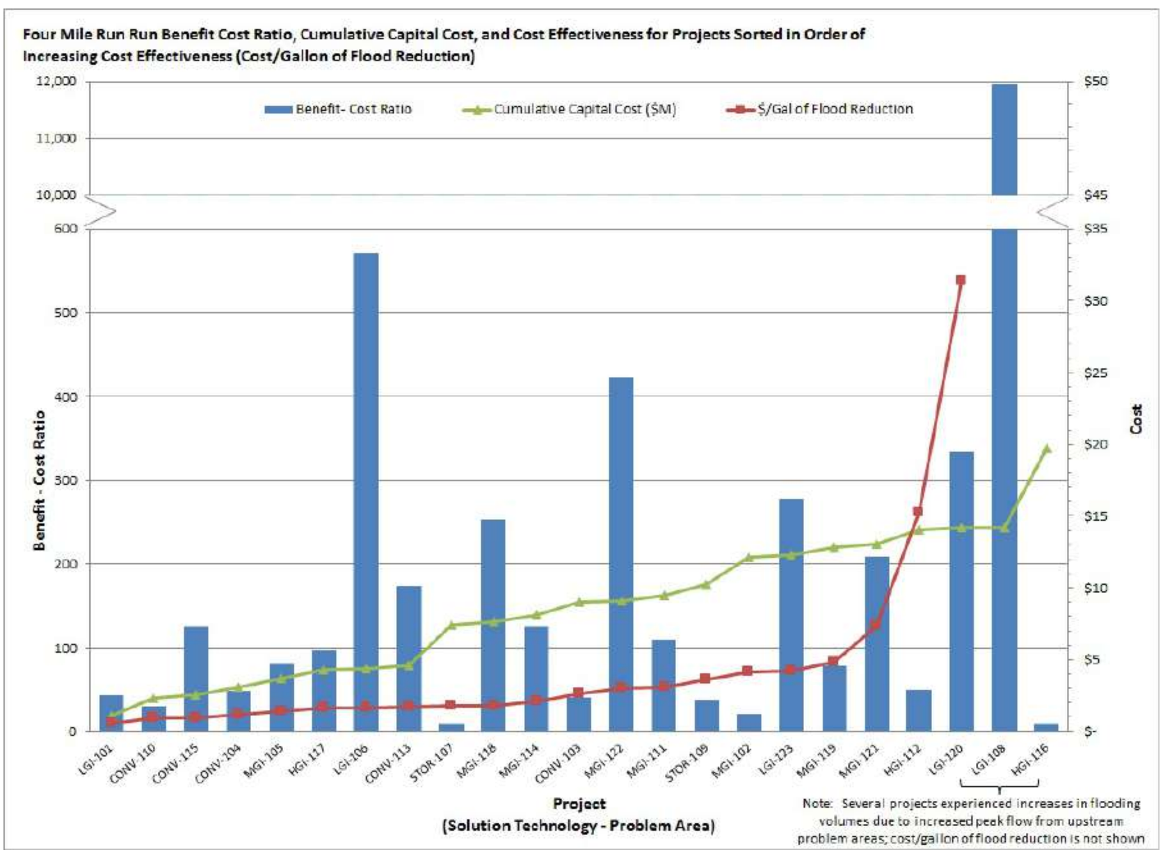
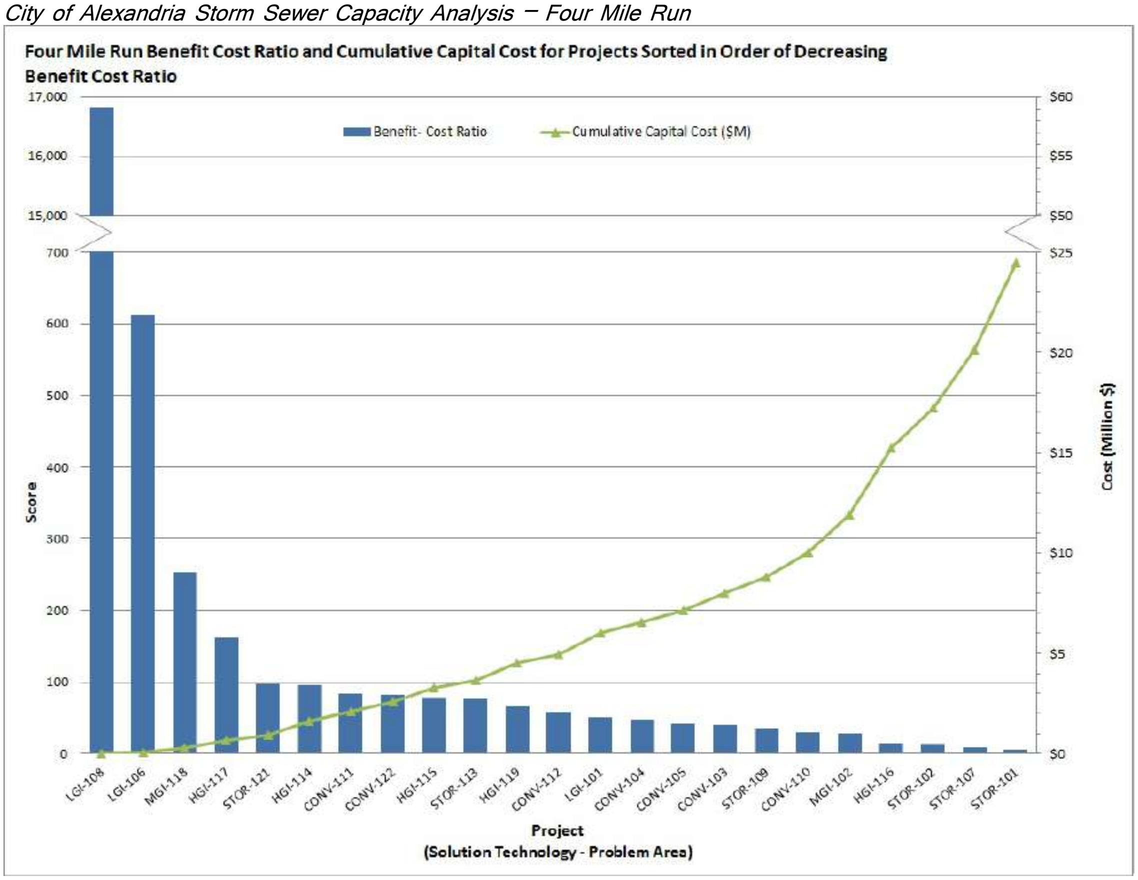
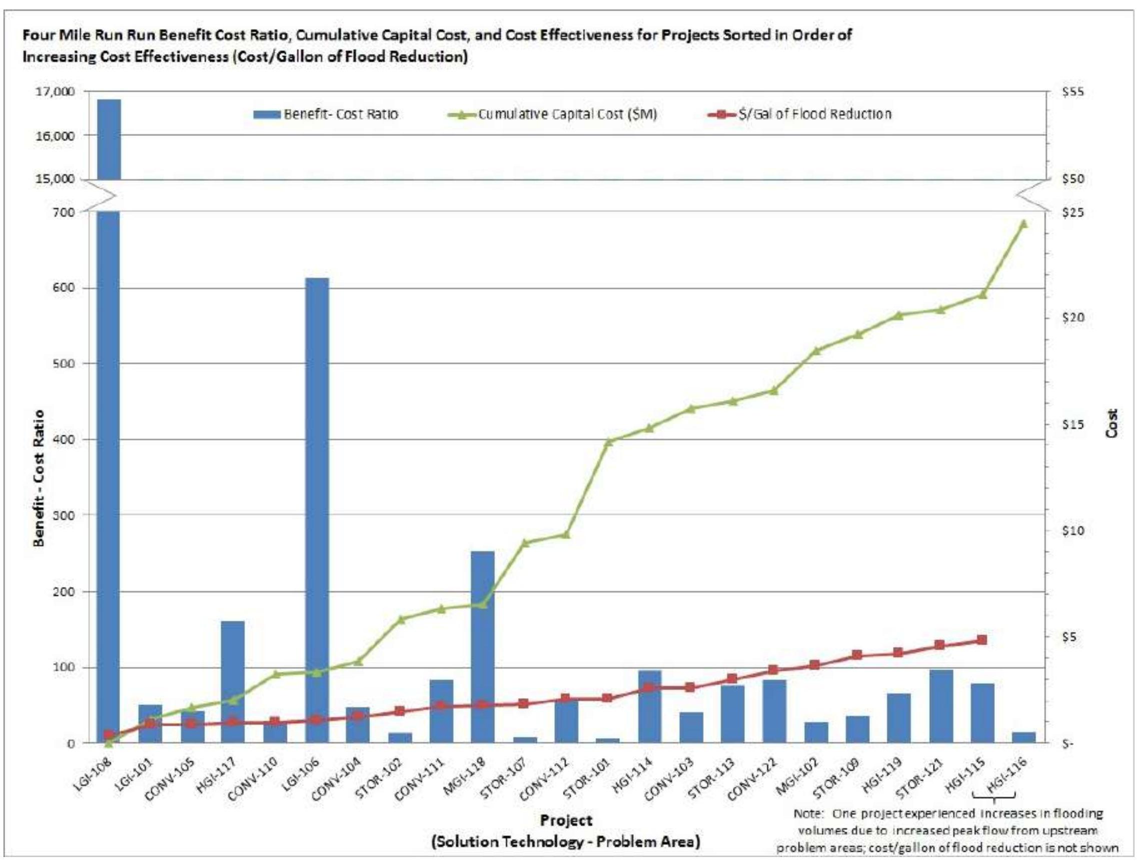


FIGURE 5-13
Alternative 3: Highest-priority Problems Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run





SECTION 6

Summary

The objectives of Task 4 were to 1) identify and prioritize capacity problems based on modeling results from Task 2 of this project, and 2) develop and prioritize solutions to address those problems. The first objective was accomplished in two steps. The first step included evaluating each stormwater junction in the drainage network using a scoring system to identify problems based on several criteria, including the severity of flooding, proximity to critical infrastructure and roadways, identification of problems by City staff and the public, and opportunity for overland relief. In the next step, high-scoring junctions (that is, higher-priority problems) were grouped together to form high-priority problem areas. In total, 23 high-priority problem areas were identified in the Four Mile Run watershed.

The second objective involved developing and prioritizing solutions to address capacity limitations within the 23 high-priority problem areas. To accomplish this objective, strategies involving different technologies were examined, including improving conveyance by increasing hydraulic capacity, reducing capacity limitations by adding distributed storage to the system, and reducing stormwater inflows by implementing GI. Each of these strategies required a different modeling approach. Conveyance improvements were modeled by increasing pipe diameter in key locations within the problem area, storage was added as storage nodes based on a preliminary siting exercise, and GI was modeled as a reduction in impervious area at three different implementation levels: high, medium, and low. A single model run was set up and run for each strategy addressing all 23 high-priority problem areas and the results were compiled for the alternative and prioritization evaluation. Solutions were evaluated based on several criteria, including drainage improvement and flood reduction, environmental compliance, sustainability and social benefits, asset management and maintenance implications, constructability, and public acceptance. Planning-level capital costs were developed for each solution to facilitate a benefit cost analysis and prioritization process.

The results of the solution identification and prioritization analysis show the following:

- Solution technology performance:
  - GI generally has the greatest overall benefit as defined by the solution evaluation scoring system described in this report.
  - Conveyance solutions and storage solutions generally provide the greatest flood reduction of the technologies and approaches analyzed in Four Mile Run.
  - Combination of conveyance or storage projects combined with GI generally provides the greatest benefit and flood reduction.
- Costs:
  - Low level of GI implementation generally has the greatest cost/benefit score but do not meet minimum threshold for flood reduction occasionally.
  - Conveyance and storage projects generally provide the most economical stormwater volume reduction in terms of dollars per gallon of flood reduction within a high-priority problem area.
  - Combination of conveyance and GI generally provides the greatest overall benefit/cost score.

The following three watershed-wide alternatives were developed:

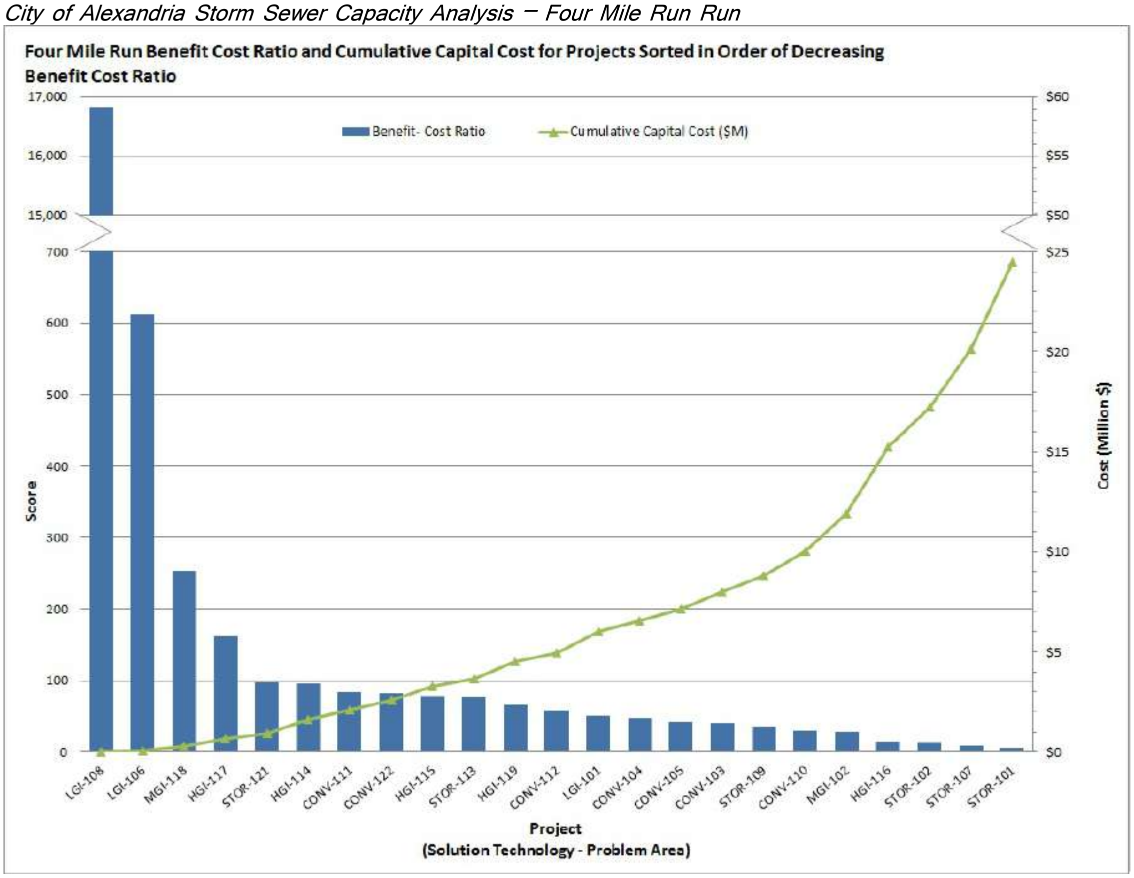
- Alternative 1: Most cost-effective solution for each problem area (lowest dollar-per-gallon of flood reduction)
- Alternative 2: Best benefit/cost ratio for each problem area (highest benefit/cost ratio)
- Alternative 3: Combination of projects to resolve the highest-priority problem areas

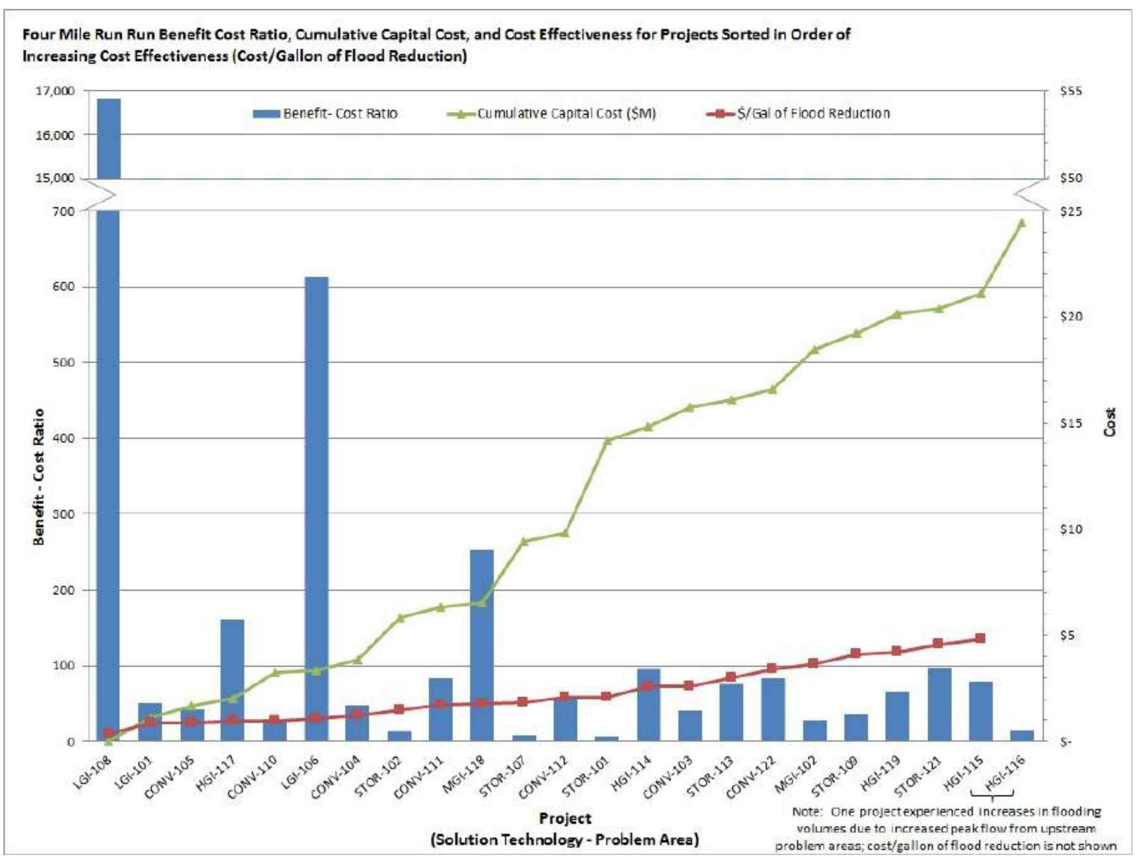
The results for each alternative generally reflect the objective of that particular alternative. A summary of the results was provided in Table 5-7. The watershed-wide results show that all three alternatives provide potential advantages when compared to the others. Alternative 1 has the best cost efficiency in terms of cost of flood reduction, but lowest overall benefit, Alternative 2 provides the greatest cost/benefit, but lowest flood reduction, and Alternative 3 provides the greatest total benefit score, but has the highest capital cost. Since the objective of this study is to provide flood reduction and relieve capacity limitations in the identified problem areas, Alternative 3 is the recommended alternative due to the amount of flood reduction achieved relative to cost and overall benefit. Though this alternative does not have the highest benefit or benefit/cost score of the three watershed-wide alternatives, Alternative 3 provides similar cost efficiency to Alternative 1, but with a higher overall benefit score. Two suggested prioritizations of watershed-wide Alternative 3 projects are provided in Figure 6-1; projects can be prioritized either based on overall benefit/cost ratio or cost efficiency (cost per gallon of flood reduction).

It should be noted that the model does not include analysis on private property, but applies assumed runoff loads as inputs to the public conveyance system. The City chose not to include existing private or most public stormwater management facilities (for example, detention and retention ponds) upstream of the modeled collection system because of the limited available information on these facilities and a concern that the facilities may not be performing as designed. When the City moves forward into detailed evaluation and design of selected projects, it will be important to fully evaluate and account for the benefits of any existing stormwater management facilities.

The hydraulic modeling results and costs presented in this report should be reviewed with the understanding that several assumptions were made to fill data gaps in the hydraulic model, and proposed solutions and costs were developed on a planning level.

FIGURE 6-1
Alternative 3: Highest-priority Problems Prioritization Results
City of Alexandria Storm Sewer Capacity Analysis – Four Mile Run Run





SECTION 7
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Appendix A
Conveyance Solutions

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Four Mile Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Proposed Shape	Existing Diameter/ Height (ft) x Width (ft)	Proposed Diameter/ Height (ft) x Width (ft)	Conduit Slope	Number of Barrels	Roughness
101	011649STMP	000270CB	001213ND	24.7	Circular	1	2.5	3.81	1	0.013
101	012812STMP	000333CB	001353ND	59.2	Circular	1	2	4.28	1	0.013
101	012878STMP	000334CB	002187SMH	44.5	Circular	1	1.5	6.35	1	0.013
101	014107STMP	000339CB	002755SMH	156.2	Circular	2.5	3	1.73	1	0.013
101	013313STMP	000642CB	003508SMH	18.0	Circular	1.5	3	9.77	1	0.013
101	011651STMP	008316IN	000270CB	37.4	Circular	1	1.5	9.49	1	0.013
101	012823STMP	007328IN	000334CB	16.8	Circular	1	1.5	6.35	1	0.013
101	010827STMP	008516IN	001352ND	53.7	Circular	1.25	2.5	6.38	1	0.013
101	010913STMP	008517IN	008516IN	24.7	Circular	1.25	2	4.22	1	0.013
101	010920STMP	008523IN	001349ND	2.3	Rectangular	1.25	3	0.00	2	0.013
101	010923STMP	008525IN	001349ND	37.9	Circular	1.25	2	1.97	1	0.013
101	010922STMP	008526IN	008525IN	10.6	Circular	1.25	2	1.97	1	0.013
101	010921STMP	008527IN	008525IN	65.8	Circular	1.25	2	1.97	1	0.013
101	011680STMP	002062SMH	001213ND	23.8	Circular	4.5	6.5	0.62	1	0.013
101	010823STMP	002157SMH	001351ND	11.1	Circular	1.25	1.5	28.71	1	0.021
101	012807STMP	002160SMH	002749SMH	57.6	Circular	3.5	4.5	0.87	1	0.013
101	010918STMP	002161SMH	002162SMH	277.7	Circular	4	5	0.29	1	0.013
101	011234STMP	002162SMH	002150SMH	89.6	Circular	4	4.5	0.45	1	0.013
101	012822STMP	002187SMH	002759SMH	40.9	Circular	4.5	5.5	1.25	1	0.013
101	014377STMP	002206SMH	002867ND	33.7	Circular	2.5	4.5	2.18	1	0.013
101	010872STMP	002707SMH	002062SMH	70.0	Circular	4.5	6.5	0.77	1	0.013
101	010873STMP	002708SMH	002711SMH	303.8	Circular	3.5	5	0.65	1	0.013
101	013371STMP	002711SMH	003508SMH	68.1	Circular	3.5	4.5	1.09	1	0.013
101	014266STMP	002749SMH	002163SMH	83.9	Circular	4	5	1.06	2	0.013
101	009896STMP	002750SMH	002153SMH	281.1	Circular	4	5.5	0.85	2	0.013
101	014237A	002756SMH	001350ND	268.2	Circular	4.5	6.5	0.58	1	0.013
101	013372STMP	003508SMH	002759SMH	204.4	Circular	3.5	4.5	1.00	1	0.013
101	011681STMP	001213ND	002187SMH	201.1	Circular	4.5	6	0.62	1	0.013
101	014272STMP	001349ND	002751SMH	89.7	Circular	2.5	3	2.54	1	0.013
101	014237B	001350ND	001352ND	17.8	Circular	4.5	6.5	0.58	1	0.013
101	014237D	001351ND	002868ND	234.6	Circular	4.5	6	0.58	2	0.013
101	014237C	001352ND	001351ND	19.6	Circular	4.5	6.5	0.58	1	0.013
101	014235STMP	001353ND	002756SMH	289.2	Circular	4.5	6	0.78	1	0.013
101	012827STMP	001355ND	000339CB	19.9	Circular	1	2	0.33	1	0.013
101	014379STMP	002867ND	002749SMH	20.2	Circular	5	6	0.58	2	0.014
102	011703STMP	000089CB	001054ND	5.4	Circular	1.25	4.5	1.19	1	0.013
102	011628STMP	006409IN	001834SMH	30.5	Circular	1	1.5	2.61	1	0.013

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Four Mile Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Proposed Shape	Existing Diameter/ Height (ft) x Width (ft)	Proposed Diameter/ Height (ft) x Width (ft)	Conduit Slope	Number of Barrels	Roughness
102	011699STMP	006442IN	001788SMH	12.9	Circular	1.25	2	1.69	1	0.013
102	011702STMP	006443IN	000089CB	34.0	Circular	1.25	3	1.19	1	0.013
102	010917STMP	007361IN	002159SMH	140.9	Circular	1.5	2	1.02	1	0.013
102	011700STMP	001788SMH	001789SMH	148.8	Circular	2.5	4.5	1.69	1	0.013
102	014225STMP	001789SMH	001054ND	133.4	Circular	2.5	5	1.19	1	0.013
102	010013STMP	001814SMH	001828SMH	22.7	Circular	2.5	4.5	0.62	1	0.013
102	010783STMP	001815SMH	001834SMH	236.9	Circular	1.25	2.5	1.13	1	0.013
102	010012STMP	001828SMH	006441IN	98.7	Circular	2.5	4	1.28	1	0.013
102	011697STMP	001829SMH	001788SMH	148.2	Circular	1.75	3.5	1.35	1	0.013
102	011423STMP	001831SMH	001829SMH	39.0	Circular	1.5	3.5	0.54	1	0.013
102	010010STMP	001834SMH	001830SMH	72.1	Circular	1.25	2.5	2.61	1	0.013
102	012895STMP	001852SMH	002195SMH	112.2	Circular	3	3.5	0.63	2	0.013
102	014265STMP	001852SMH	002194SMH	438.7	Circular	2.5	3.5	0.41	2	0.013
102	010678STMP	001877SMH	001814SMH	219.8	Circular	2.5	4	0.84	1	0.013
102	014100STMP	002193SMH	001356ND	80.6	Circular	2	3.5	1.19	1	0.013
102	014283STMP	002193SMH	002160SMH	275.3	Circular	2	4	0.38	1	0.013
102	012082STMP	002194SMH	002206SMH	112.3	Circular	2.5	4	0.40	1	0.013
102	014281STMP	002195SMH	002193SMH	132.5	Circular	2	3.5	0.62	2	0.013
102	012081STMP	002200SMH	002194SMH	74.3	Circular	2	3.5	1.67	1	0.013
102	014224STMP	001054ND	001852SMH	408.6	Circular	2.5	3.5	1.19	2	0.013
102	012083STMP	001356ND	002160SMH	194.9	Circular	2	5	0.05	2	0.013
103	011397STMP	006740IN	000258CB	63.9	Circular	1	1.5	6.05	1	0.013
103	011398STMP	006742IN	006740IN	25.2	Circular	1	1.5	6.03	1	0.013
103	014204STMP	001957SMH	001190ND	154.7	Circular	3.5	5.5	0.76	1	0.013
103	010995STMP	001958SMH	001959SMH	9.7	Rectangular	2.25	6	0.00	2	0.013
103	010996STMP	001959SMH	001190ND	15.8	Circular	2.25	3.5	3.48	1	0.013
103	010994STMP	001960SMH	001958SMH	101.5	Circular	2.25	4	1.74	1	0.013
103	010998STMP	002028SMH	001960SMH	23.7	Circular	2.25	4.5	0.93	1	0.013
103	011000STMP	002034SMH	002028SMH	111.6	Circular	2.25	3	1.85	2	0.013
103	014205A	002035SMH	001199ND	153.7	Circular	4	7	0.47	1	0.013
103	012398STMP	002044SMH	002034SMH	338.1	Circular	2.5	4.5	0.69	1	0.013
103	014206STMP	001190ND	002035SMH	87.3	Circular	3.5	5	2.14	1	0.013
104	011319STMP	000254CB	001191ND	57.7	Circular	1.25	2	7.62	1	0.013
104	011327STMP	000256CB	006696IN	246.0	Circular	1	1.5	0.41	1	0.013
104	011315STMP	006695IN	006696IN	16.9	Circular	1	1.5	10.04	1	0.013
104	011316STMP	006696IN	000254CB	28.7	Circular	1	2	5.53	1	0.013
104	011318STMP	006697IN	000254CB	15.7	Circular	1	1.5	7.62	1	0.013

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Four Mile Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Proposed Shape	Existing Diameter/ Height (ft) x Width (ft)	Proposed Diameter/ Height (ft) x Width (ft)	Conduit Slope	Number of Barrels	Roughness
104	011325STMP	006701IN	000256CB	36.6	Circular	1	1.5	7.38	1	0.013
104	014414STMP	001189ND	006695IN	379.0	Circular	1.5	1.5	3.95	2	0.013
104	014384C	001191ND	001957SMH	164.4	Circular	3.5	5.5	0.80	1	0.013
104	014384B	001192ND	001191ND	219.6	Circular	3.5	4.5	0.91	1	0.013
105	012214STMP	000177CB	002025SMH	24.6	Circular	1	2	8.20	1	0.013
105	012065STMP	000181CB	001180ND	27.2	Circular	0.833	1	11.09	1	0.013
105	012067STMP	000182CB	002027SMH	46.2	Circular	0.833	1	4.71	1	0.013
105	012303STMP	000236CB	001179ND	18.4	Circular	0.667	1.5	3.01	1	0.013
105	011847STMP	000241CB	000242CB	49.9	Circular	1	1.5	3.39	1	0.013
105	012213STMP	006657IN	000177CB	13.6	Circular	1	2	8.20	1	0.013
105	011845STMP	006665IN	006666IN	10.4	Circular	1	1.5	3.50	1	0.013
105	011846STMP	006666IN	000241CB	113.4	Circular	1	1.5	3.50	1	0.013
105	010991STMP	006703IN	001956SMH	34.1	Circular	1.25	2	0.95	1	0.013
105	010992STMP	006704IN	006703IN	16.4	Circular	1.25	2	0.95	1	0.013
105	012199STMP	002008SMH	001181ND	112.3	Circular	2.5	5.5	0.04	1	0.013
105	012217STMP	002025SMH	002026SMH	19.5	Circular	1.25	2	8.20	1	0.013
105	012070STMP	002027SMH	001917SMH	250.0	Circular	3	4.5	0.60	1	0.013
105	011027STMP	001918SMH	001956SMH	147.8	Circular	3.5	4.5	0.95	1	0.013
105	014362C	001163ND	002008SMH	15.4	Circular	2	3	0.25	1	0.013
105	012071STMP	001179ND	002027SMH	13.2	Circular	1.25	1.5	3.01	1	0.013
105	012058STMP	001181ND	002026SMH	124.0	Circular	2.5	3.5	1.00	1	0.013
106	012410STMP	006789IN	002696SMH	181.0	Circular	3	4.5	0.58	1	0.013
106	012409STMP	002696SMH	002705SMH	87.4	Circular	3	4	1.25	1	0.021
106	012415STMP	002700SMH	006792IN	118.3	Circular	2.5	3	3.27	1	0.013
106	010943STMP	002702SMH	002700SMH	43.5	Circular	2.5	3.5	2.48	1	0.013
107	012628STMP	008723IN	002221SMH	14.4	Circular	1.5	3	4.51	1	0.013
107	012629STMP	008724IN	008723IN	23.2	Circular	1.25	2.5	9.63	1	0.013
107	012630STMP	008725IN	008726IN	18.2	Circular	1.25	3	1.57	1	0.013
107	012631STMP	008726IN	008727IN	17.4	Circular	1.25	3	1.57	1	0.013
107	012633STMP	008728IN	008727IN	14.5	Circular	1.25	2	23.80	1	0.013
107	013351STMP	002217SMH	002218SMH	247.7	Circular	3	4.5	1.61	1	0.013
107	011562STMP	002218SMH	002220SMH	159.3	Circular	3	4.5	2.18	1	0.013
107	011563STMP	002219SMH	002220SMH	49.9	Circular	1	3	5.43	1	0.013
107	012636STMP	002220SMH	002221SMH	50.9	Circular	3	4.5	1.85	1	0.013
107	014391STMP	001361ND	001362ND	39.2	Special	5	6.5	2.24	1	0.013
107	014065STMP	001362ND	008727IN	44.3	Circular	3.5	4	2.24	1	0.013
108	010679STMP	001870SMH	001877SMH	281.5	Circular	2.5	3.5	1.45	1	0.013

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Four Mile Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Proposed Shape	Existing Diameter/ Height (ft) x Width (ft)	Proposed Diameter/ Height (ft) x Width (ft)	Conduit Slope	Number of Barrels	Roughness
109	011345STMP	000330CB	002747SMH	27.8	Circular	1.25	2	0.85	1	0.013
109	011346STMP	007167IN	002746SMH	24.7	Circular	1	1.5	0.85	1	0.013
109	012945STMP	002209SMH	002210SMH	48.0	Circular	5.67	8	0.15	2	0.013
109	014090STMP	004050SMH	002209SMH	143.8	Circular	3.5	4	2.80	1	0.013
109	011897STMP	002744SMH	002208SMH	92.0	Special	6.33	8	0.17	1	0.013
109	011344STMP	002746SMH	000330CB	12.6	Circular	1	2	0.85	1	0.013
109	014392STMP	002069ND	004050SMH	29.9	Rectangular	3.5	8	0.04	2	0.01
110	009822STMP	000245CB	002680SMH	10.9	Circular	0.833	1	6.62	1	0.013
110	009835STMP	000248CB	002683SMH	11.8	Circular	0.833	1.5	2.46	1	0.013
110	012339STMP	000251CB	001948SMH	13.1	Circular	0.833	1.5	2.43	1	0.013
110	012341STMP	000252CB	001949SMH	12.2	Circular	0.833	1.5	2.39	1	0.013
110	012344STMP	000253CB	001950SMH	39.0	Circular	1.25	1.5	6.08	1	0.013
110	012345STMP	006691IN	000253CB	9.6	Circular	0.833	1.5	6.08	1	0.013
110	009825STMP	001916SMH	002680SMH	262.5	Circular	1.75	2.5	4.50	1	0.013
110	012340STMP	001948SMH	001949SMH	43.2	Circular	2.25	4.5	2.43	1	0.013
110	012342STMP	001949SMH	001950SMH	103.2	Circular	2.25	4.5	2.39	1	0.013
110	012343STMP	001950SMH	001953SMH	389.9	Circular	2.5	4.5	2.49	1	0.013
110	012901STMP	001953SMH	002791SMH	121.0	Circular	2.5	4.5	2.30	1	0.013
110	012500STMP	002102SMH	002686SMH	28.8	Circular	2	2.5	4.41	1	0.013
110	009824STMP	002680SMH	002681SMH	49.1	Circular	1.75	2.5	6.62	1	0.021
110	009827STMP	002681SMH	002683SMH	239.3	Circular	2	2.5	4.48	1	0.013
110	014249STMP	002683SMH	001166ND	21.0	Circular	2	3	2.46	1	0.013
110	012334STMP	002684SMH	001948SMH	239.3	Circular	2.25	4	3.09	1	0.013
110	014247STMP	002685SMH	001187ND	130.4	Circular	2	3	4.00	1	0.013
110	011652STMP	002686SMH	002685SMH	98.4	Circular	2	2.5	4.41	1	0.013
110	012897STMP	002791SMH	002731SMH	154.9	Circular	2.5	4.5	2.73	1	0.013
110	009834STMP	001117ND	001166ND	195.9	Circular	1	1.5	6.75	1	0.013
110	014250STMP	001166ND	002684SMH	22.6	Circular	2	3	6.75	1	0.013
110	014248STMP	001187ND	002684SMH	42.7	Circular	2.25	3	3.18	1	0.013
110	014245STMP	001225ND	002102SMH	51.5	Circular	1.25	2	2.14	1	0.021
111	012029A	006843IN	001231ND	70.8	Circular	1.25	2	1.94	1	0.013
111	012599STMP	002110SMH	002111SMH	23.2	Circular	2.25	3.5	3.28	1	0.013
111	012603STMP	002111SMH	002132SMH	124.3	Circular	2.25	3.5	2.91	1	0.013
111	012600STMP	002112SMH	002110SMH	179.9	Circular	2	3.5	3.36	1	0.013
111	012608STMP	002114SMH	002113SMH	147.6	Circular	2	2.5	2.11	1	0.013
111	014122STMP	002115SMH	004032SMH	137.9	Circular	1.5	2	9.26	1	0.013
111	012524STMP	002116SMH	002115SMH	146.0	Circular	1.5	2	7.24	1	0.013

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Summary of Conveyance Solutions developed for Four Mile Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Proposed Shape	Existing Diameter/ Height (ft) x Width (ft)	Proposed Diameter/ Height (ft) x Width (ft)	Conduit Slope	Number of Barrels	Roughness
111	012527STMP	002117SMH	002116SMH	249.7	Circular	1.5	2	5.30	1	0.013
111	014123STMP	004032SMH	004033SMH	12.4	Circular	1.5	2.5	12.22	1	0.013
111	014124STMP	004033SMH	002112SMH	108.1	Circular	2	3	8.34	1	0.013
111	012029B	001231ND	002117SMH	50.3	Circular	1.25	1.5	3.22	1	0.013
112	012113STMP	002235SMH	002234SMH	72.9	Circular	2	3.5	2.99	1	0.013
112	014179STMP	002237SMH	002235SMH	356.7	Circular	2	3	4.41	1	0.013
112	012682STMP	002239SMH	002240SMH	40.1	Circular	1.25	1.5	7.27	1	0.013
112	011358STMP	002240SMH	002241SMH	208.9	Circular	1.25	2	4.28	1	0.013
112	014181STMP	002241SMH	001224ND	277.5	Circular	1.25	2	5.77	1	0.013
112	012994STMP	001220ND	002237SMH	13.3	Circular	1.5	2.5	4.41	1	0.013
112	014180STMP	001224ND	002237SMH	28.7	Circular	1.25	2.5	5.00	1	0.021
112	009637C	001237ND	001220ND	18.3	Circular	1.75	2.5	4.41	1	0.013
112	009637B	001238ND	001237ND	154.2	Circular	1.75	2.5	5.87	1	0.013
113	014157A	008870IN	001363ND	16.3	Circular	2	3	6.81	1	0.013
113	009644STMP	008872IN	008873IN	32.7	Circular	1.5	2	7.92	1	0.013
113	009991STMP	008873IN	002843SMH	75.1	Circular	1.5	2	7.43	1	0.013
113	014159STMP	002317SMH	001370ND	144.0	Circular	2	2.5	5.67	1	0.013
113	014068STMP	002843SMH	008870IN	54.7	Circular	2	3	6.81	1	0.013
113	011188STMP	002848SMH	008872IN	128.7	Circular	1.5	2	4.07	1	0.011
113	014157B	001363ND	002842SMH	38.2	Circular	2	3	6.81	1	0.013
113	014158STMP	001370ND	002843SMH	50.1	Circular	2	2.5	6.10	1	0.013
114	012273STMP	000164CB	001157ND	18.2	Circular	1.25	2	1.02	1	0.013
114	012297STMP	000167CB	002001SMH	36.8	Circular	1	1.5	10.51	1	0.013
114	012274STMP	006622IN	000164CB	19.7	Circular	1	2	1.02	1	0.013
114	012298STMP	006629IN	000167CB	14.5	Circular	0.833	1.5	10.51	1	0.013
114	012292STMP	006630IN	002003SMH	22.0	Circular	1.25	1.5	3.24	1	0.013
114	012394STMP	006773IN	000260CB	50.3	Circular	0.833	1.5	7.92	1	0.013
114	012242STMP	001980SMH	001976SMH	56.0	Circular	1.25	2.5	0.86	1	0.013
114	012279STMP	001986SMH	001157ND	200.7	Circular	1.5	2.5	1.02	1	0.013
114	012268STMP	001997SMH	001998SMH	42.2	Circular	1.25	1.5	5.24	1	0.013
114	012275STMP	001998SMH	002001SMH	225.6	Circular	2	3.5	0.82	1	0.013
114	014227STMP	002001SMH	001160ND	48.5	Circular	2	4	0.72	1	0.013
114	012395STMP	002002SMH	002044SMH	220.7	Circular	2	4	0.75	1	0.013
114	012289STMP	002003SMH	002002SMH	34.1	Circular	1.25	1.5	3.24	1	0.013
114	012299STMP	002005SMH	006630IN	68.1	Circular	1.25	1.5	3.24	1	0.013
114	012243STMP	001976SMH	001977SMH	45.3	Circular	1.25	2.5	0.31	1	0.013
114	011636A	001977SMH	001145ND	172.7	Circular	1.25	2.5	1.02	1	0.013

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Four Mile Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Proposed Shape	Existing Diameter/ Height (ft) x Width (ft)	Proposed Diameter/ Height (ft) x Width (ft)	Conduit Slope	Number of Barrels	Roughness
114	011636B	001145ND	001986SMH	49.1	Circular	1.25	2.5	1.02	1	0.013
114	012276STMP	001157ND	001998SMH	72.3	Circular	1.5	3	1.02	1	0.013
114	014226STMP	001160ND	002002SMH	75.1	Circular	2	4	0.72	1	0.013
115	010655STMP	006288IN	006287IN	24.1	Circular	1.25	2	1.57	1	0.013
115	010689STMP	001797SMH	001867SMH	208.4	Circular	2	2.5	1.08	1	0.013
115	010659STMP	001867SMH	001869SMH	55.5	Circular	2	3	0.94	1	0.013
115	010661STMP	001868SMH	001869SMH	15.9	Circular	1.25	2	5.29	1	0.013
115	010662STMP	001869SMH	001813SMH	193.3	Circular	2	4	0.57	1	0.013
116	011216STMP	000263CB	002049SMH	18.5	Circular	0.833	1.5	1.38	1	0.013
116	010695STMP	006313IN	001798SMH	23.8	Circular	1	2.5	2.07	1	0.013
116	011090STMP	006314IN	0001049ND	2.9	Circular	1	2.5	2.05	1	0.013
116	010706STMP	006806IN	002704SMH	91.3	Circular	4.5	6.5	0.18	2	0.013
116	011219STMP	006780IN	002049SMH	322.1	Circular	1.25	2	1.29	1	0.013
116	010693STMP	001798SMH	002050SMH	20.7	Circular	1.25	2.5	6.86	1	0.013
116	014207STMP	001799SMH	001050ND	27.7	Circular	3.5	4.5	0.34	1	0.013
116	011094STMP	001800SMH	006316IN	106.5	Circular	1.5	2.5	1.49	1	0.021
116	011095STMP	001801SMH	001800SMH	153.1	Circular	1.5	2.5	0.75	1	0.021
116	011217STMP	001809SMH	002049SMH	142.8	Circular	1.75	2.5	1.63	1	0.013
116	012404STMP	002046SMH	002047SMH	32.7	Circular	2	3	1.07	1	0.013
116	014146STMP	002048SMH	0001049ND	235.3	Circular	2.25	3.5	1.35	1	0.013
116	012405STMP	002049SMH	002046SMH	115.0	Circular	2	3	1.38	1	0.013
116	011091STMP	002050SMH	001799SMH	111.0	Circular	2.5	3.5	1.01	1	0.013
116	011223STMP	002051SMH	006806IN	108.0	Circular	4.5	6.5	0.91	1	0.013
116	014200STMP	002704SMH	001202ND	31.3	Circular	4.5	6.5	0.64	1	0.013
116	014147STMP	0001049ND	002050SMH	29.9	Circular	2.25	3.5	2.05	1	0.013
116	014208STMP	001050ND	006747IN	428.7	Circular	2.5	3	0.34	2	0.013
116	014205B	001199ND	001205ND	84.2	Circular	4	6.5	0.67	1	0.013
116	014205D	001200ND	001201ND	18.5	Circular	4	6.5	0.67	1	0.021
116	014202STMP	001201ND	002051SMH	15.6	Circular	4.5	6.5	0.67	1	0.013
116	014205C	001205ND	001200ND	37.8	Circular	4	6.5	0.67	1	0.013
117	010817STMP	006861IN	002088SMH	173.9	Circular	1	2.5	1.63	1	0.013
117	010815STMP	008482IN	008483IN	164.6	Circular	1	2	1.21	1	0.013
117	010816STMP	008483IN	006861IN	38.7	Circular	1	3	0.32	1	0.013
117	009969STMP	002089SMH	002087SMH	207.0	Circular	1.25	2.5	1.98	1	0.013
118	011508STMP	007459IN	008424IN	23.0	Circular	1.25	2.5	2.95	1	0.013
118	012448STMP	008397IN	002066SMH	73.3	Circular	1.25	2	1.38	1	0.013
118	012483A	008423IN	001259ND	183.2	Circular	1.25	2.5	0.65	2	0.013

Appendix A - Conveyance Solutions

Summary of Conveyance Solutions developed for Four Mile Run High-Priority Problem Areas

Problem Area	FacilityID	Upstream Node Name	Downstream Node Name	Length ft	Proposed Shape	Existing Diameter/ Height (ft) x Width (ft)	Proposed Diameter/ Height (ft) x Width (ft)	Conduit Slope	Number of Barrels	Roughness
118	012495STMP	008424IN	008423IN	28.1	Circular	1.25	2.75	0.20	2	0.013
118	012446STMP	002066SMH	002065SMH	63.9	Circular	2	3.5	0.25	1	0.013
118	012447STMP	002067SMH	002066SMH	124.9	Circular	1.5	2.5	0.93	2	0.013
118	013170STMP	002828SMH	007459IN	90.7	Circular	1.25	2.5	2.95	1	0.013
118	012483B	001259ND	002067SMH	64.6	Circular	1.25	2.5	0.89	1	0.013
119	014381A	000335IN	000073ND	94.5	Circular	3	5	0.39	1	0.013
119	001496STMP	000133SMH	000134SMH	184.6	Circular	2.5	3.5	1.68	1	0.013
119	001503STMP	000134SMH	000184SMH	26.0	Circular	2.5	3.5	1.50	1	0.013
119	001189STMP	000136SMH	000335IN	142.5	Circular	3	4.5	0.54	1	0.013
119	001195STMP	000184SMH	000185SMH	43.4	Circular	2.5	3	2.47	1	0.013
119	000637STMP	000185SMH	000136SMH	129.4	Circular	3	4.5	0.72	1	0.013
119	014381B	000073ND	000072ND	57.8	Circular	3	5	0.39	1	0.013
120	002000STMP	001026IN	000389SMH	75.9	Circular	2	2.5	6.38	1	0.013
121	003166STMP	000563SMH	000564SMH	24.3	Circular	1.5	2	3.00	1	0.013
121	003167STMP	000564SMH	000565SMH	100.5	Circular	1.5	2.5	3.00	1	0.013
121	003169STMP	000565SMH	000566SMH	114.3	Circular	1.5	2	6.80	1	0.013
121	003203STMP	000571SMH	000563SMH	326.6	Circular	1.25	2.5	0.92	1	0.013
121	003216STMP	000577SMH	000578SMH	199.3	Circular	1.25	2	0.86	1	0.013
122	005440STMP	003733IN	003734IN	253.0	Circular	1.25	2	0.43	1	0.013
122	005441STMP	003734IN	003735IN	240.9	Circular	1.25	2	0.49	1	0.013
122	005442STMP	003735IN	003736IN	129.9	Circular	1.5	2	0.08	2	0.013
122	005753STMP	003736IN	003737IN	93.7	Circular	1.5	2	0.39	2	0.013
122	005757STMP	003737IN	001199SMH	198.4	Circular	1.5	2	0.20	2	0.013
122	005755STMP	003738IN	001199SMH	11.3	Circular	1.25	1.5	4.36	1	0.013
122	005734STMP	001194SMH	001195SMH	118.1	Circular	1.5	2.5	1.73	1	0.013
122	005758STMP	001199SMH	001194SMH	95.7	Circular	1.25	2	1.99	2	0.013
123	014050STMP	000365SMH	000160ND	148.1	Circular	2	3	5.98	1	0.013
123	014049STMP	000160ND	000328SMH	105.2	Circular	2	3	6.05	1	0.013

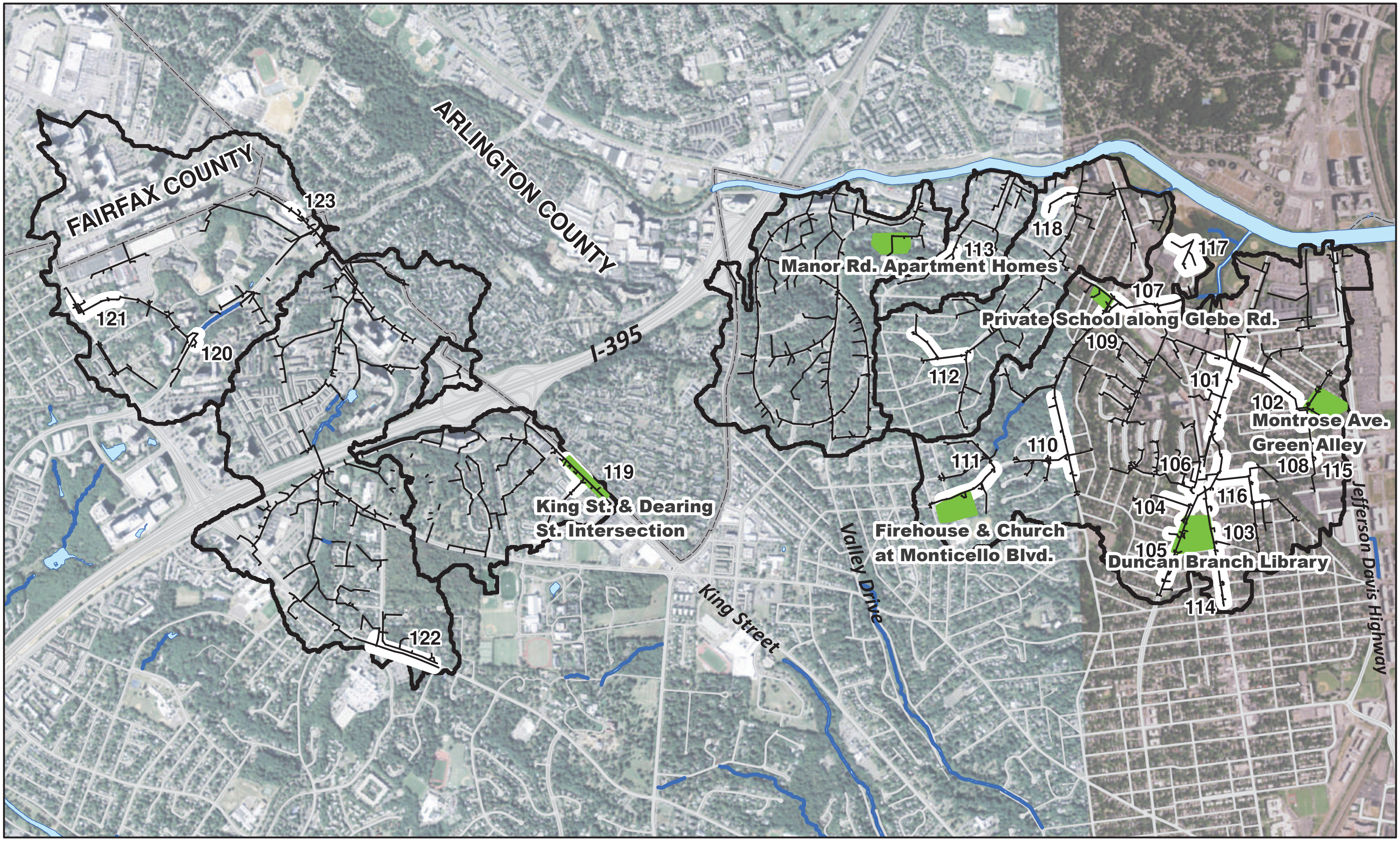
Appendix B
Storage Solutions

Appendix B - Storage Solutions

Summary of Storage Solutions developed for Four Mile Run High-Priority Problem Areas

Problem Area	Storage ID	Overflow Node	Discharge Node	Storage Area (ac)	Storage Area (ft^2)	Overflow Weir Crest (ft)	Overflow Weir Crown (ft)	Storage Invert Elevation (ft)	Storage Rim Elevation (ft)	Storage Depth (ft)	Storage Volume (ft^3)	Notes
101	1	002162SMH	002156SMH	0.46	19,960	9.85	12.55	4.47	9.85	5.38	107,345	
101	2	002750SMH	002153SMH	0.16	6,834	11.07	13.47	4.69	11.07	6.38	43,603	
101	3	002868ND	002166SMH	0.08	3,485	12.83	13.90	9.04	12.831783	3.79	13,215	
101	4	001351ND	002166SMH	0.10	4,481	13.68	15.90	9.04	13.681624	4.64	20,800	
101	5	002756SMH	002200SMH	0.31	13,298	15.44	17.64	10.15	15.44	5.29	70,358	
101	8	002755SMH	002164SMH	0.26	11,511	13.69	14.39	12.77	16.98	4.21	48,494	water max depth is 4.65 ft
101	9	002759SMH	002756SMH	0.47	20,578	11.16	13.36	10.94	17.34	6.40	131,698	water max depth is 3.54 ft
101	10	002187SMH	001353ND	0.15	6,417	16.98	18.13	13.20	17.85	4.65	29,838	water max depth is 4.51 ft
102	6	001852SMH	002200SMH	0.27	11,727	17.34	19.54	10.15	13.69	3.54	41,524	water max depth is 4.21 ft
102	7	002193SMH	002161SMH	0.20	8,752	17.85	19.55	6.65	11.16	4.51	39,473	water max depth is 6.40 ft
102	11	001789SMH	002200SMH	0.13	5,795	19.64	23.84	10.15	19.64	9.49	54,995	
103	12	006747IN	001199ND	0.30	13,242	24.08	25.18	19.70	24.0761	4.37	57,908	
104	13	001956SMH	001957SMH	0.69	30,052	30.24	35.54	26.00	30.24	4.24	127,422	
107	17	002221SMH	002090SMH	0.41	18,056	183.13	186.98	8.00	11.36	3.36	60,668	
107	18	002218SMH	002220SMH	1.18	51,313	104.08	107.18	9.30	14	4.70	241,170	
109	20	002208SMH	002748SMH	0.35	15,096	192.95	197.65	24.00	27.35	3.35	50,571	
109	24	002718SMH	001360ND	0.69	29,902	11.36	14.06	24.00	34	10.00	299,017	
110	15	002681SMH	000248CB	0.15	6,627	15.78	19.48	94.00	104	10.00	66,267	
111	14	001231ND	006832IN	0.73	31,967	155.35	159.45	172.00	182	10.00	319,668	
113	22	002317SMH	002842SMH	0.14	6,132	27.35	31.45	70.00	80	10.00	61,323	
113	23	002843SMH	002842SMH	0.16	6,861	185.67	190.97	66.92	72	5.08	34,854	
114	25	001977SMH	001145ND	0.14	6,214	87.57	91.77	36.90	39.9153	3.01	18,713	
117	29	006867IN	002088SMH	1.68	73,082	76.35	80.55	1.44	5.88304	4.44	324,707	
117	30	002089SMH	002088SMH	0.62	27,143	41.64	44.67	1.44	7.36289	5.92	160,763	
118	31	002067SMH	002073SMH	0.14	5,978	39.92	44.67	6.58	10.0531	3.47	20,761	
119	16	000335IN	000140SMH	1.69	73,518	249.05	253.88	189.90	192.95	3.05	224,229	
120	21	000389SMH	000317SMH	1.48	64,347	266.03	267.11	168.00	178	10.00	643,472	
121	26	000571SMH	000565SMH	0.82	35,662	263.98	264.88	241.05	249.053993	8.01	285,583	
121	32	000563SMH	000567SMH	1.45	63,146	5.88	7.20	232.00	242	10.00	631,465	
122	27	003734IN	001194SMH	1.19	51,763	7.36	9.88	260.83	264	3.17	163,984	
122	28	001199SMH	001201SMH	0.92	39,870	10.05	11.32	253.73	262	8.27	329,721	
123	19	000365SMH	000393SMH	0.72	31,517	246.30	248.22	134.00	144	10.00	315,174	

Appendix C
Green Infrastructure Concept Plans



Legend

Concept Locations

City of Alexandria Streams

Water Bodies

Subwatersheds

Green Infrastructure Concept Plans Locations and High Priority Problem Areas

Task 4 Problem and Solution Identification and Prioritization for Four Mile Run, City of Alexandria, Virginia

CH2MHILL Baker

Potential Sites for Task 4 Concept Development in Four Mile Run Watershed

PREPARED FOR: City of Alexandria TE&S

COPY TO: File

PREPARED BY: Michael Baker Jr., Inc.

DATE: June 10, 2014

The following is documentation of the sites identified for green infrastructure (GI) concept development in the Four Mile Run watershed. In addition to field notes that describe the sites and the proposed GI, the pros and cons of GI implementation are also listed. The inspections were conducted in December 2013. The conceptual plan corresponding to each site can be found as an attachment to this documentation.

King St. & Dearing St. Intersection

Grass Median where Bioretention is Proposed (facing northwest)

Grass Median where Bioretention is Proposed (facing southeast)

Program Type: Green Streets

GI Concepts: Bioretention/Planters, Porous Pavement

Field Notes:

- Location is a median along King Street and an adjacent residential parking lot.
- Grass swales in grass median areas between the main road and the access road collect runoff.
- The storm sewer system is located in the grass median area.
- Some of the storm sewer system grates were observed to be clogged by leaves and other debris.
- The area is mostly residential with some nearby commercial buildings.
- Proposed GI Concept
  - Install a bioretention area in the grass median.
  - Install porous pavement in the nearby parking lot and along the access road where cars are permitted to park.

Pros:

- The existing storm sewer system is deep so the GI facilities can be tied into the existing system.
- Curb cuts can be used to direct water into the grass median since water is already flowing in this direction.

Cons:

- There are several trees in the grass median that may need to be removed or replanted in the GI facility.
- There is overhead electric that may need to be relocated.
- Construction access may be difficult due to the residential buildings and the busy traffic patterns of King Street.
- Precautions will have to be taken to ensure the porous pavement does not become clogged.

Manor Rd. Apartment Homes

Parking along Street (facing west)

Circular Median and Apartment Parking Lot (facing northeast)

Program Type: Green Parking

GI Concepts: Bioretention/Planters, Porous Pavement

Field Notes:

- Location is a large apartment complex with adjacent roads and parking lots.
- Proposed GI Concept
    - Install bioretention bump outs along the road.
    - Install porous pavement along the road and in the parking lot.
    - Convert the grass circular median into a bioretention area and divert road and roof runoff to it.

Pros:

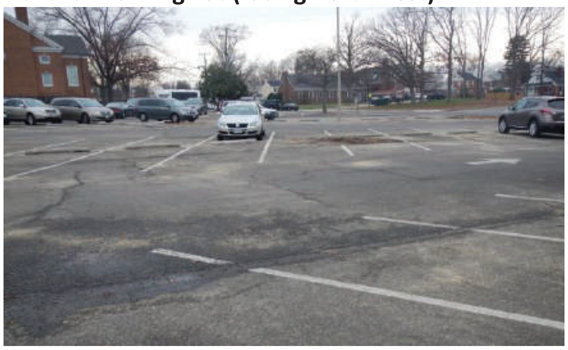
- The existing storm sewer system is about 5.2 feet below ground, which make tie-ins easy for the proposed GI facilities.
- There is a large circular median area where runoff is already flowing toward.

Cons:

- The apartment complex is privately owned and will require coordination with property owner to implement GI facilities on private property.
- The site visit was conducted during the workday and numerous cars were seen parked along the street. Therefore, parking is very important in this area and precautions will have to be taken during construction to ensure there is ample room for parking. In addition, the proposed bioretention areas along the street will remove several parking spaces and may be controversial.
- Precautions will have to be taken to ensure the porous pavement does not become clogged.

Firehouse & Church at Monticello Blvd.

Church Parking Lot (facing northwest)



Open Grass Area near Firehouse (facing southwest)

Program Type: Green Firehouse and Church

GI Concepts: Bioretention/Planters, Porous Pavement, Cisterns

Field Notes:

- Location is a City firehouse and Westminster Presbyterian Church.
- The church parking lot does not have any stormwater infrastructure.
- An employee of the firehouse stated that the firehouse is scheduled to be torn down and rebuilt in 2016; however, the project has not been funded yet.
- Proposed GI Concept:
    - Install porous pavement in the church parking lot.
    - Install two bioretention cells in the grass areas near the firehouse to treat parking lot and roof runoff.
    - Install cisterns around the church to treat roof runoff.

Pros:

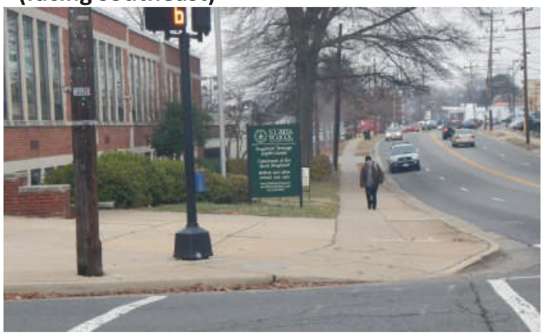
- The existing storm sewer system is about 5 feet below ground and should be easy to tie into.
- There is a large area of roof and parking lot runoff available to treat.

Cons:

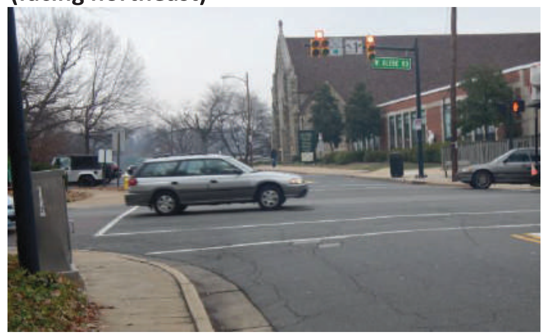
- The church is privately owned and will require coordination with the property owner to implement GI facilities on private property.
- The existing parking lot has several drainage patterns and it may need to be resurfaced or regraded.
- Precautions will have to be taken to ensure the porous pavement does not become clogged.

Private School along Glebe Rd.

Looking at the School along Glebe Road (facing southeast)



Looking at the School along Russell Road (facing northeast)



Program Type: Green School

GI Concepts: Bioretention/Planters, Porous Pavement, Green Roof

Field Notes:

- Location is a large private school on the corner of West Glebe road and Russell Road.
- Proposed GI Concept:
  - Install a green roof on the school.
  - Install tree box filters along Glebe Road to treat road runoff.
  - Install porous pavement in the parking lot.

Pros:

- There are major pipe capacity issues in this location.
- A large amount of stormwater is conveyed through the storm sewer system to this location.
- The existing storm sewer system is about 7 feet below ground and should be easy to tie into.

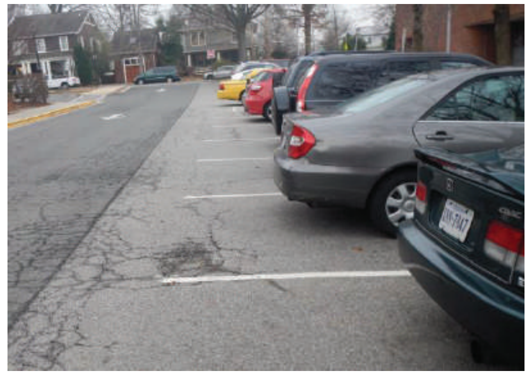
Cons:

- The school is privately owned and it will take some cooperation to implement GI facilities on private property.
- There is continuous heavy traffic through the intersection and along both roads.
- There are space limitations because the area is built out with very little space available to install GI facilities.
- The project is near the bottom of the watershed where decreasing stormwater volume results in improving conveyance in a shorted length of pipe as opposed to a project near the top of the watershed.
- Precautions will have to be taken to ensure the porous pavement does not become clogged.
- Construction access may be difficult.

Duncan Branch Library

Grass Strip between Commonwealth Ave and Sidewalk (facing northeast)

Library Parking Lot (facing south)



Program Type: Green Library

GI Concepts: Bioretention/Planters, Porous Pavement, Green Roof

Field Notes:

- Location is a City library along Commonwealth Avenue.
- Along Uhler Avenue, an underground device was observed that could be a stormwater treatment device. Further investigation is needed to determine if the roof runoff is already being treated by this device.
- Since the project is in a high profile area, it will need to be well maintained as aesthetics will be important.
- Proposed GI Concept:
    - Install tree box filters in the grass strip between the sidewalk and Commonwealth Avenue to treat road runoff.
    - Install porous pavement in the library parking lot to the east of the building.
    - Install a green roof on portions of the building.

Pros:

- The project is in a high profile area because it is next to a library and it is a good opportunity for outreach.
- The existing storm sewer system is about 7.5 feet below ground and should be easy to tie into.

Cons:

- Commonwealth Avenue has a large amount of pedestrian and vehicular traffic.
- There is uncertainty regarding the current treatment of stormwater.
- Construction access may be difficult.
- Precautions will have to be taken to ensure the porous pavement does not become clogged.

Montrose Ave. Green Alley

At Montrose Avenue (facing southeast)

At the End of the Alley (facing northwest)

Program Type: Green Alley

GI Concepts: Porous Pavement

Field Notes:

- The location is along an alley that provides access to the backyards/garages of row homes on either side.
- The row homes all have disconnected downspouts.
- The alley is connected to Montrose Avenue but is a dead end on the opposite side.
- There is a slotted drain in the center of the alley and a throated inlet off of a small paved area to the side.
- Proposed GI Concept:
    - Install porous pavement in the alley to create a “green alley”.

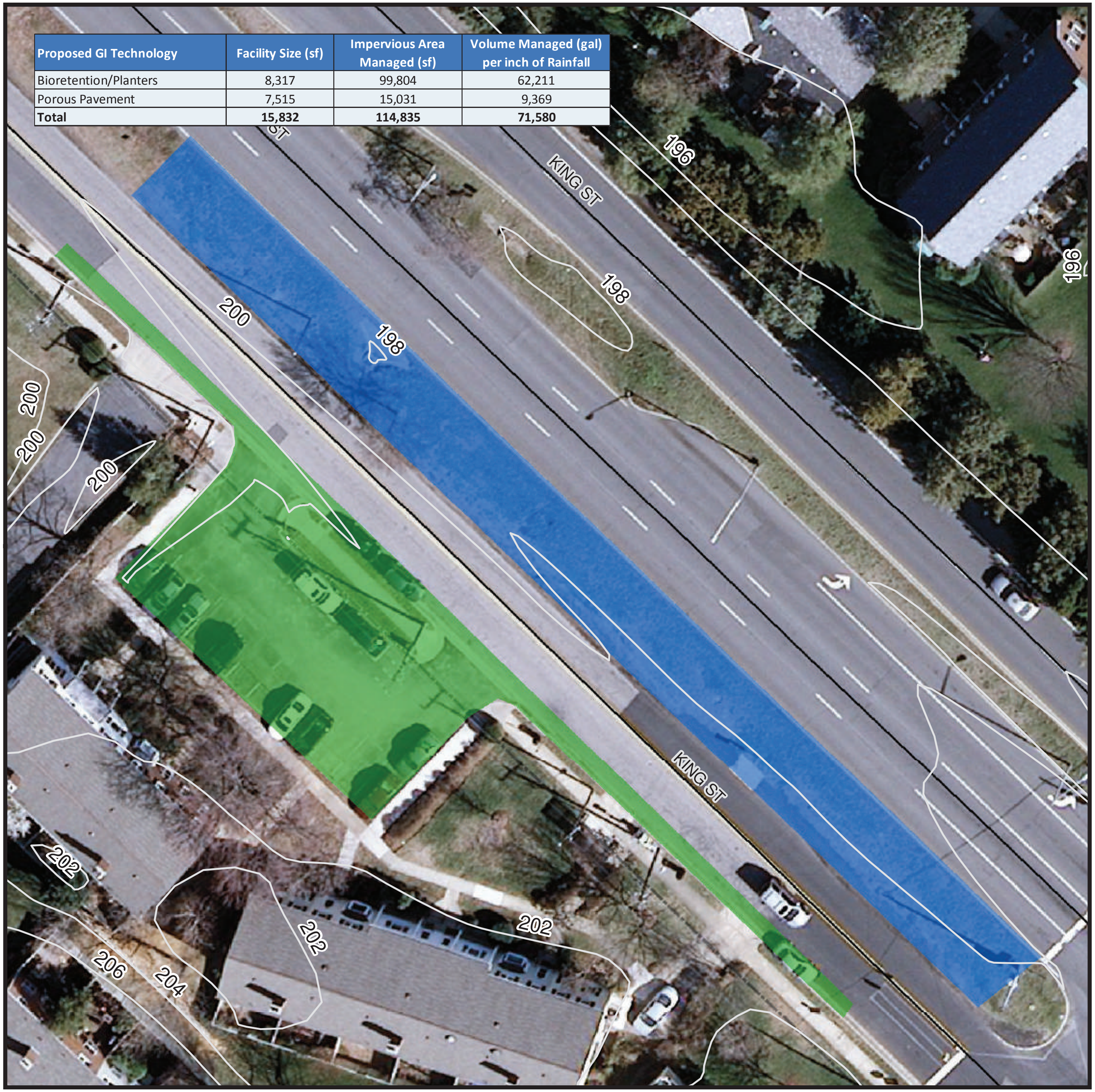
Pros:

- The existing alley is in poor condition and needs to be repaved.
- The existing storm sewer system is about 6 feet below ground and should be easy to tie into.
- The majority of the alley is relatively flat.

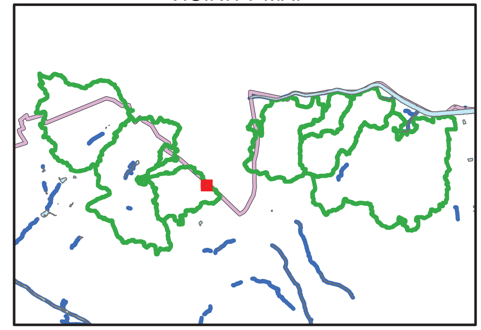
Cons:

- Construction access may be difficult.
- The project is near the bottom of the watershed where decreasing stormwater volume results in improving conveyance in a shorted length of pipe as opposed to a project near the top of the watershed.
- Precautions will have to be taken to ensure the porous pavement does not become clogged.

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Bioretention/Planters	8,317	99,804	62,211
Porous Pavement	7,515	15,031	9,369
Total	**15,832**	**114,835**	**71,580**



VICINITY MAP



Legend

- City of Alexandria Streams
- Water Bodies
- Contours (ft)
- Alexandria Boundary

Green Infrastructure Concepts

- Bioretention/Planters
- Cisterns
- Green/Blue Roofs
- Porous Pavement
- Stream Daylighting
- Surface Storage (Blue Streets)

N

0 20 40 80

Feet

King St. & Dearing St. Intersection

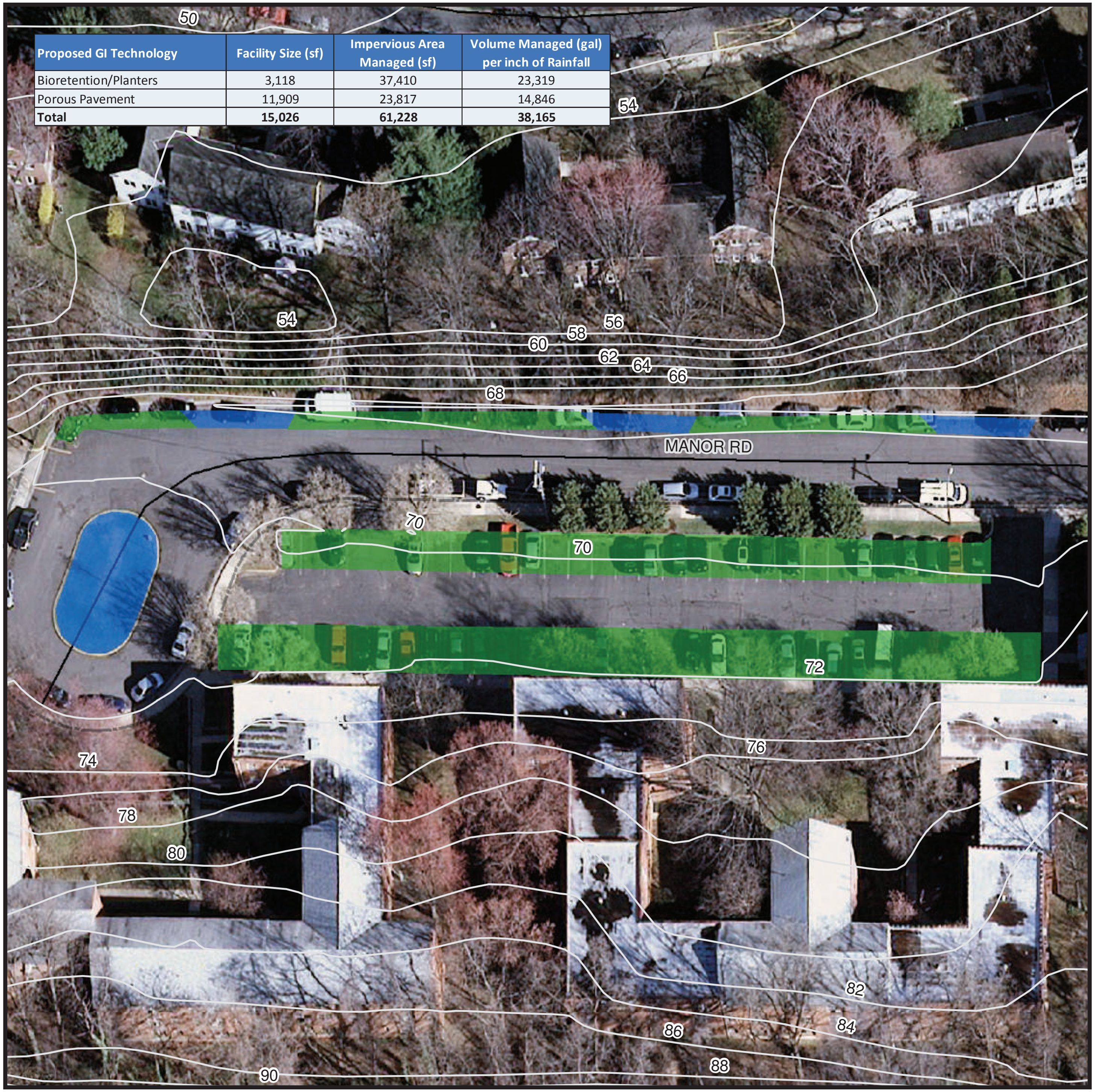
Green Streets
- Bioretention/Planters, Porous Pavement

Task 4 - Identify Problems and Develop Solutions

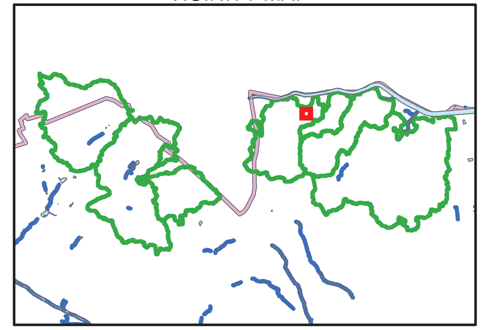
City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL Baker

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Bioretention/Planters	3,118	37,410	23,319
Porous Pavement	11,909	23,817	14,846
Total	**15,026**	**61,228**	**38,165**



VICINITY MAP



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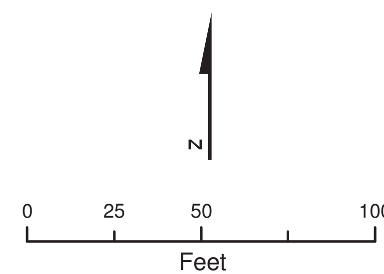


Manor Rd. Apartment Homes

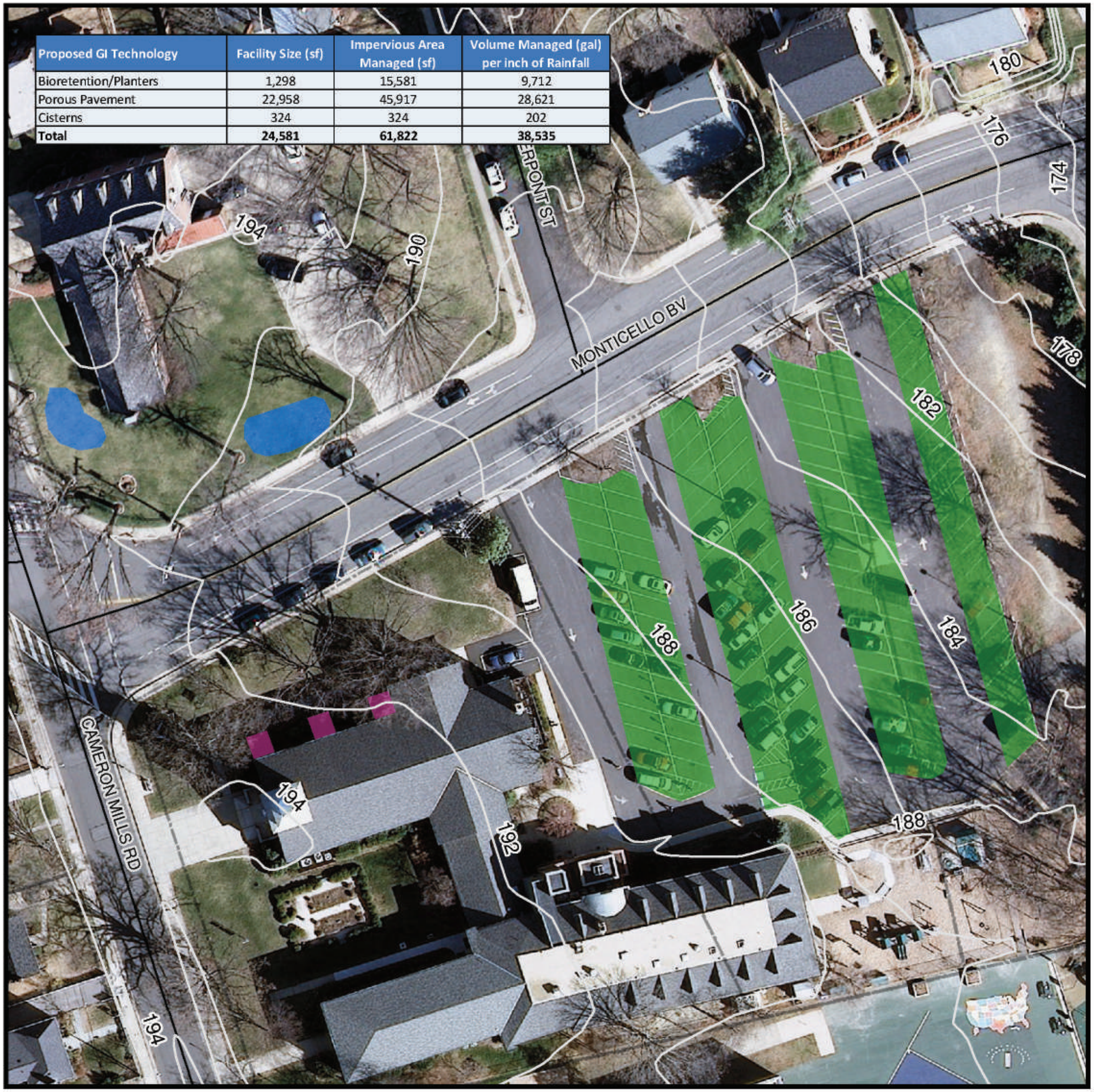
Green Parking
- Bioretention/Planters, Porous Pavement

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL Baker

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Bioretention/Planters	1,298	15,581	9,712
Porous Pavement	22,958	45,917	28,621
Cisterns	324	324	202
Total	**24,581**	**61,822**	**38,535**



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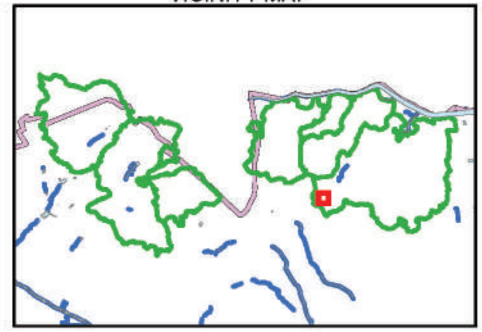

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- Bioretention/Planters
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- Surface Storage (Blue Streets)

N

0 30 60 120
Feet

Firehouse & Church at Monticello Blvd.

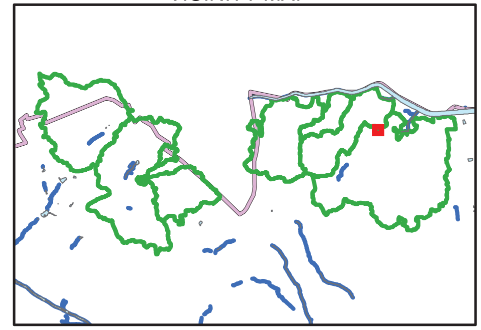
Green Firehouse and Church
- Bioretention/Planters, Porous Pavement, Cisterns

Task 4 - Identify Problems and Develop Solutions
City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL Baker

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Bioretention/Planters	93	1,110	692
Porous Pavement	4,119	8,238	5,135
Green Roof	11,305	11,305	7,047
Total	**15,517**	**20,654**	**12,874**

VICINITY MAP



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N

0 20 40 80

Feet

Private School along Glebe Rd.

Green School

- Bioretention/Planters, Porous Pavement, Green Roof

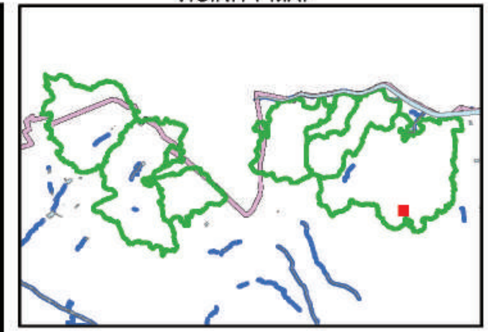
Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL Baker

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Bioretention/Planters	179	2,145	1,337
Porous Pavement	2,462	4,923	3,069
Green Roof	3,838	3,838	2,393
Total	**6,479**	**10,906**	**6,798**

VICINITY MAP



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N

0 15 30 60
Feet

Duncan Branch Library

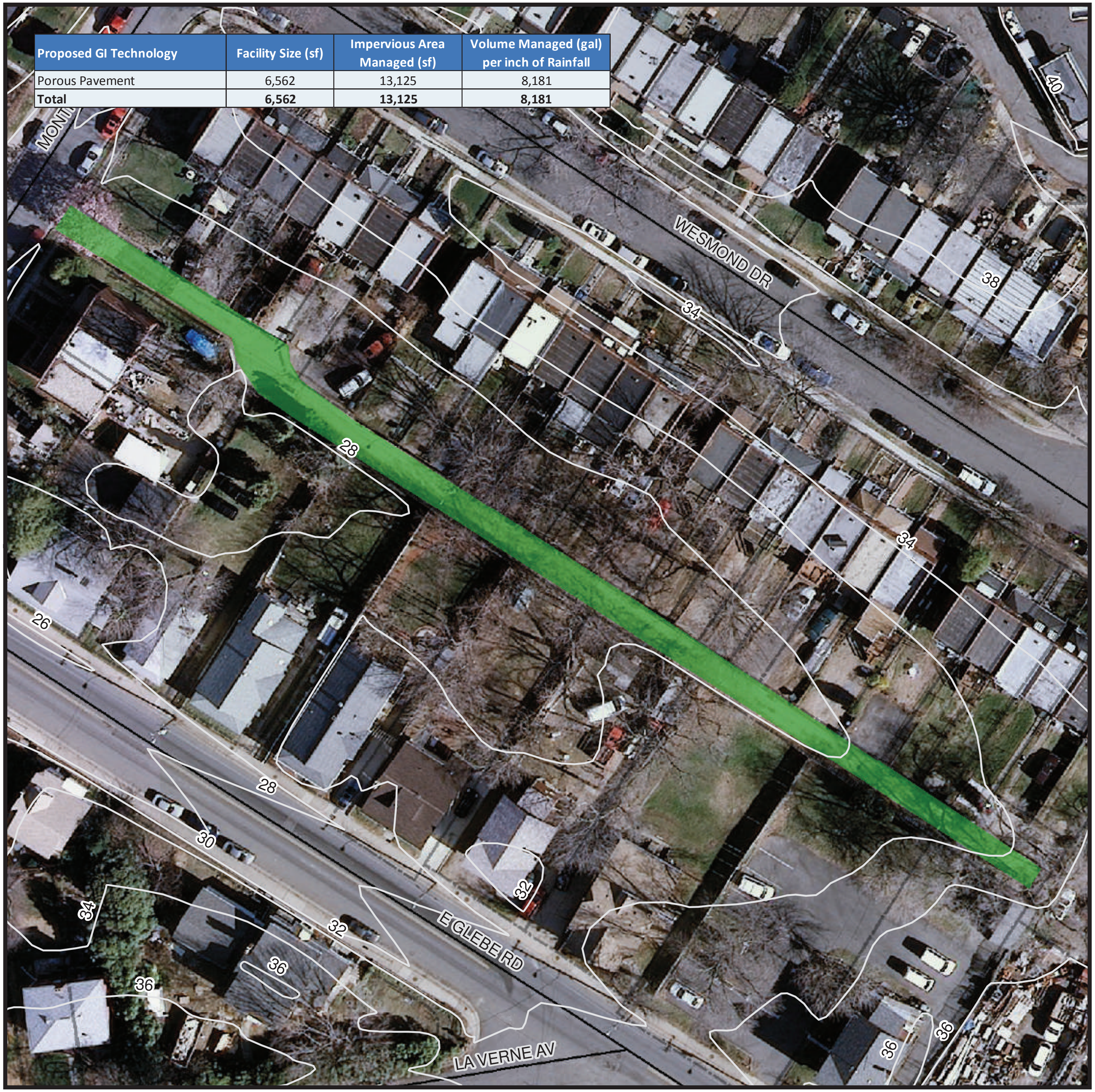
Green Library
- Bioretention/Planters, Porous Pavement, Green Roof

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL Baker

Proposed GI Technology	Facility Size (sf)	Impervious Area Managed (sf)	Volume Managed (gal) per inch of Rainfall
Porous Pavement	6,562	13,125	8,181
Total	**6,562**	**13,125**	**8,181**



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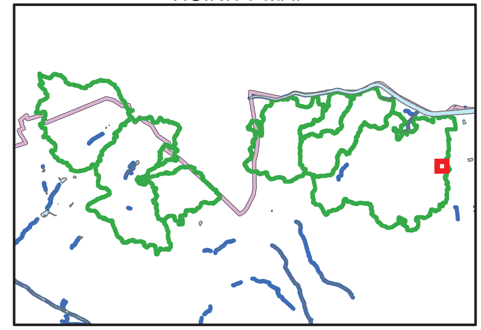

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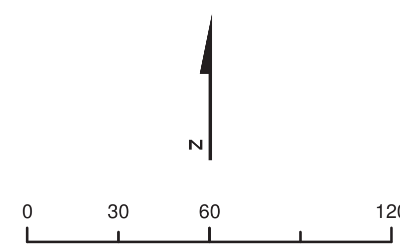


Montrose Ave. Green Alley

Green Alley
- Porous Pavement

Task 4 - Identify Problems and Develop Solutions

City of Alexandria Storm Sewer Capacity Analysis

CH2MHILL Baker

FACT SHEET: BIORETENTION AND STORMWATER PLANTERS

Rain garden in a public park setting in Lancaster, PA

Right-of-way bioretention planting in Syracuse, NY

Bioretention areas (often called Rain Gardens) are shallow surface depressions planted with specially selected native vegetation to treat and capture runoff and are sometimes underlain by sand or a gravel storage/infiltration bed. Bioretention is a method of managing stormwater by pooling water within a planting area and then allowing the water to infiltrate into the garden soils. In addition to managing runoff volume and mitigating peak discharge rates, this process filters suspended solids and related pollutants from stormwater runoff.

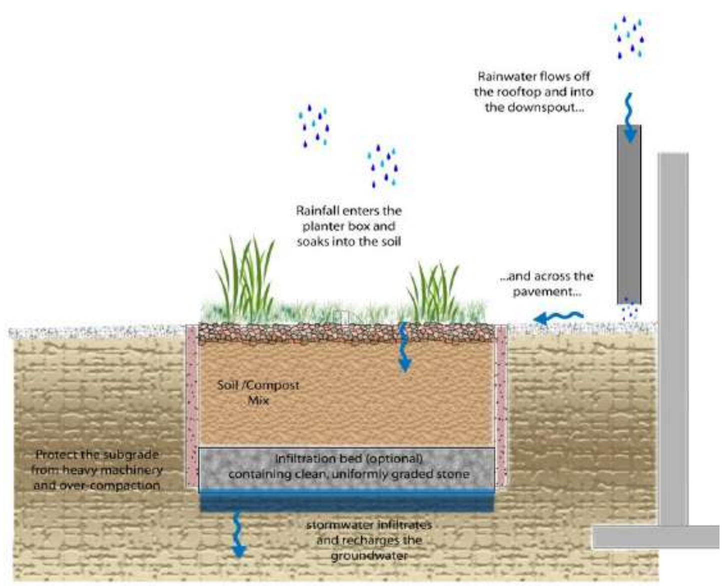
Bioretention can be designed into a landscape as a garden feature that helps to improve water quality while reducing runoff quantity. Rain Gardens can be integrated into a site with a high degree of flexibility and can balance nicely with other structural management systems including porous pavement parking lots, infiltration trenches, and non-structural stormwater BMPs. Bioretention areas typically require little maintenance once fully established and often replace areas that were intensively landscaped and required high maintenance.

A Stormwater Planter is a container or enclosed feature located either above ground or below ground, planted with vegetation that captures stormwater within the structure itself.

BENEFITS

- Volume control & GW recharge, moderate peak rate control
- Versatile w/ broad applicability
- Enhanced site aesthetics and habitat
- Potential air quality & climate benefits

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Yes (Planters)
Industrial	Yes
Retrofit	Yes
Recreational	Yes
Public/Private	Yes



Conceptual cross-section showing planter with infiltration

VARIATIONS

- Subsurface storage/infiltration bed
- Use of underdrain and/or impervious liner
- Planters – Contained (above ground), infiltration (below ground), flow-through
- Pre-treatment incorporated into design

KEY DESIGN FEATURES

- Ponding depths 6 to 18 inches for drawdown within 48 hours
- Plant selection (native vegetation that is tolerant of hydrologic variability, salts, and environmental stress)
- Amended or engineered soil as needed
- Stable inflow/outflow conditions and positive overflow for extreme storm events
- Planters may require flow bypass during winter
- Planters - Captured runoff to drain out in 3 to 4 hours after storm even unless used for irrigation

SITE FACTORS

- Water Table/ Bedrock Separation: 2-foot minimum, 4-foot recommended (N/A for contained planter)
- Soils: HSG A and B preferred; C & D may require an underdrain (N/A for contained planter)
- Feasibility on steeper slopes: medium
- Potential Hotspots: yes with pretreatment and/or impervious liner, yes for contained planter
- Maximum recommended drainage area loading: 15:1; not more than 1 acre to one rain garden

MAINTENANCE

- Often requires watering during establishment
- Spot weeding, pruning, erosion repair, trash removal, mulch reapplication (as needed) required 2-3x/growing season
- Maintenance tasks and costs are similar to traditional landscaping

COST

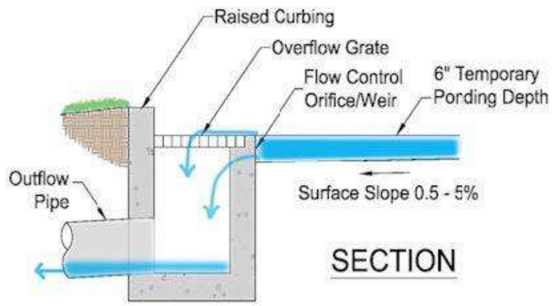
- Bioretention costs will vary depending on size/vegetation type/storage elements; typical costs $10-25/ sq. ft.

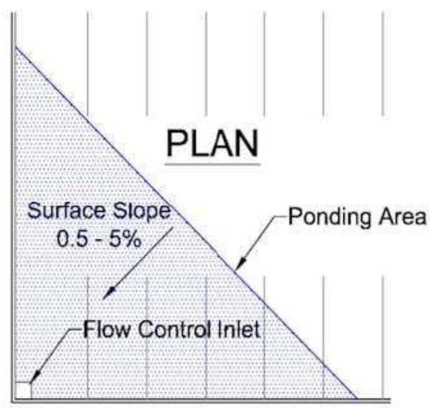
POTENTIAL LIMITATIONS

- Higher maintenance until vegetation is established
- Limited impervious drainage area to each BMP
- Requires careful selection & establishment of plants

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	High	TSS	High	Capital Cost	Medium
Groundwater Recharge	High	TP	High	Maintenance	Low/Medium
Peak Rate	Medium	TN	Medium	Winter Performance	Medium
Erosion Reduction	Medium	Temperature	Medium/High	Fast Track Potential	Medium
Flood Protection	Medium			Aesthetics	High

FACT SHEET: BLUE STREETS





Blue streets refer to the practice of temporarily detaining stormwater, delaying its release and reducing its peak flow rate into the storm sewer system.

Surface storage practices have been used traditionally on rooftops (i.e. blue roofs) and in parking lots but can also be implemented in residential streets and right-of-ways with lower traffic volumes. These "blue streets" can be a cost-effective way to manage stormwater and address surcharging without significant subsurface excavation and construction interventions.

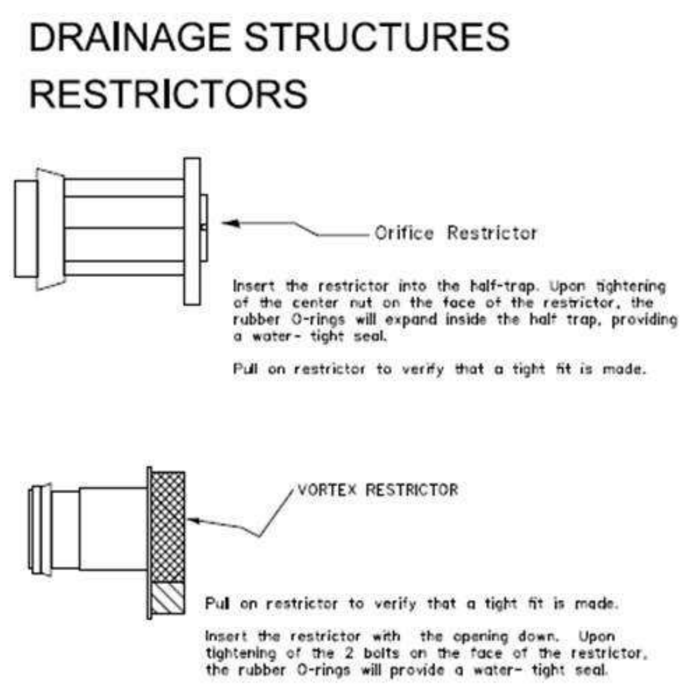
Surface storage is typically accomplished using drainage structures and retrofitting existing catch basins to feature devices such as orifice restrictors or vortex restrictors. Blue streets also emphasize minimizing the number of catch basins to the extent practical.

Blue streets (surface storage techniques) are often best implemented in alleys, low volume roads, and on private sites, for public perception and safety reasons.

BENEFITS

- Reduces stress on drainage system
- Mitigates peak rate flow
- Cost-effective technique to manage stormwater
- Short duration storage
- Reduces need for subsurface excavation and construction

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Limited
Industrial	Yes
Retrofit	Yes
Highway/Road	Limited for Highway
Recreational	Yes
Public/Private	Yes/Yes



Drainage structure restrictors are key features of surface storage and blue streets. Source: City of Chicago design manual

VARIATIONS

- Flow control structures
- Orifice restrictors
- Vortex restrictors
- Reduction in number of catch basins/inlets on a street

KEY DESIGN FEATURES

- Emergency overflows typically required
- Maximum ponding depths (less than one foot)
- Adequate surface slope to outlet
- Traffic volume, public safety, and user inconvenience must be taken into account

SITE FACTORS

- Water table to bedrock depth – N/A
- Soils – N/A
- Slope – Requires relatively low slopes to provide appreciable storage
- Potential hotspots – yes
- Maximum drainage area – relatively small DA to individual inlets (similar to conventional inlets)

MAINTENANCE

- Clean drainage structures and repair/replace parts as needed

COST

- Drainage structures restrictors range in cost, for example installing a vortex restrictor can be approximately $1000 per inlet

POTENTIAL LIMITATIONS

- Not suitable for heavily-used roadways without adequate median/shoulder space
- Excess ponding on roadways may freeze in winter conditions
- Public safety perceptions and concerns
- Does not inherently address water quality and quantity – should generally be combined with other BMPs

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Low	TSS	Low	Capital Cost	Low
Groundwater Recharge	Low	TP	Low	Maintenance	Low/Medium
Peak Rate	Medium	TN	Low	Winter Performance	Medium
Erosion Reduction	Low	Temperature	Low	Fast Track Potential	High
Flood Protection	Medium			Aesthetics	Low

FACT SHEET: CISTERNS/RAIN BARRELS

Example of above-ground cistern with vegetation screening

Cisterns (or rain barrels) are structures designed to intercept and store runoff from rooftops to allow for its reuse, reducing volume and overall water quality impairment. Stormwater is contained in the cistern structure and typically reused for irrigation or other water needs. This GI technology reduces potable water needs while also reducing stormwater discharges.

Cisterns can be located above or below ground and are containers or tanks with a larger storage capacity than a rain barrel, and often used to supplement grey water needs (i.e. toilet flushing) in a building, as well as irrigation. Rain barrels are above-ground structures connected to rooftop downspouts that collect rainwater and store it until needed for a specific use, such as landscape irrigation.

Cisterns and rain barrels can be used in suburban and urban areas where the need for supplemental onsite irrigation or other high water uses is especially apparent.

BENEFITS

- Provides supplemental water supply
- Wide applicability
- Reduces potable water use
- Related cost savings and environmental benefits
- Reduces stormwater runoff impacts

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Yes, if demand exists
Industrial	Yes
Retrofit	Yes
Highway/Road	No
Recreational	Limited
Public/Private	Yes/Yes

Rain barrel prototype example

VARIATIONS

- Cisterns – can be either underground and above ground
- Water storage tanks
- Storage beneath a usable surface using manufactured stormwater products (chambers, pipes, crates, etc.)
- Various sizes, materials, shapes, etc.

KEY DESIGN FEATURES

- Small storm events are captured with most structures
- Provide overflow for large storms events
- Discharge/use water before next storm event
- Consider site topography, placing structure upgradient of plantings (if applicable) in order to eliminate pumping needs

SITE FACTORS

- Water table to bedrock depth – N/A (although must be considered for subsurface systems)
- Soils – N/A
- Slope – N/A
- Potential hotspots – typically N/A for rooftop runoff
- Maximum drainage area – typically relatively small, based on storage capacity

MAINTENANCE

- Use stored water and/or discharge before next storm event
- Clean annually and check for loose valves, leaks, etc. monthly during active season
- May require flow bypass valves or be taken offline during the winter

COST

- Cisterns typically cost from $3 to $8/gallon/ Rain Barrels range from $75 to $300 each

POTENTIAL LIMITATIONS

- Manages only relatively small storm events which requires additional management and use for the stored water.
- Typically requires additional management of runoff
- Requires a use for the stored water (irrigation, gray water, etc.)

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Low/Medium	TSS	Medium	Capital Cost	Medium
Groundwater Recharge*	Low/Medium	TP	Medium	Maintenance	Medium
Peak Rate*	Low	TN	Low	Winter Performance	Low
Erosion Reduction	Low	Temperature	Low	Fast Track Potential	Medium/High
Flood Protection*	Low			Aesthetics	Low/Medium

**Although stand-alone cisterns are expected to have lower benefits in these categories, if combined with downspout disconnection to landscaped areas the benefits can be increased significantly.*

FACT SHEET: VEGETATED (GREEN) ROOFS AND BLUE ROOFS

Green roof (Philadelphia, PA)

Blue roof (NYC) / Photo – Gowanus Canal Conservancy

A green roof is a veneer of vegetation that is grown on and covers an otherwise conventional flat or pitched roof, endowing the roof with hydrologic characteristics that more closely match surface vegetation. The overall thickness of the veneer typically ranges from 2 to 6 inches and may contain multiple layers, such as waterproofing, synthetic insulation, non-soil engineered growth media, fabrics, and synthetic components. Vegetated roofs can be optimized to achieve water quantity and water quality benefits. Through the appropriate selection of materials, even thin vegetated covers can provide significant rainfall retention and detention functions.

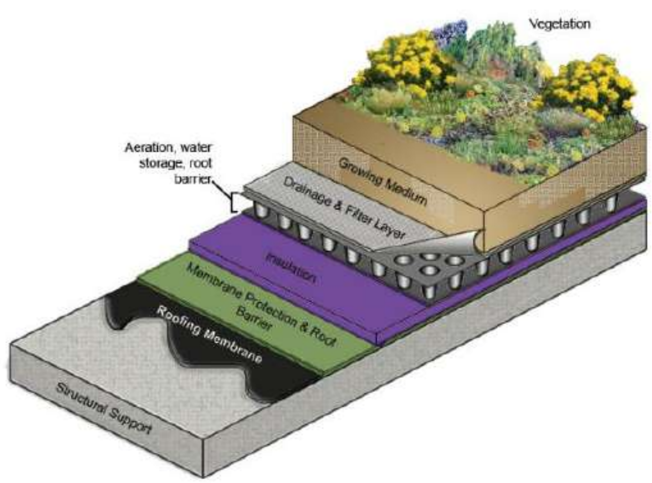
Depending on the plant material and planned usage for the roof area, modern vegetated roofs can be categorized as systems that are intensive (usually > 6 inches of substrate), semi-intensive, or extensive (<4 inches). More maintenance, higher costs and more weight are the characteristics for the intensive system compared to that of the extensive vegetated roof.

Another GI rooftop technology - **Blue roofs -** are non-vegetated systems that employ stormwater control devices to temporarily store water on the rooftop and then release it into the drainage system at a relatively low flow rate. Storage can be provided by modifying roof drains or through the use of detention trays that sometimes have a lightweight gravel media. Blue roof and green roof technologies can also be combined in a design to achieve

BENEFITS

- High volume reduction (annual basis)
- Moderate ecological value and habitat (green roofs)
- High aesthetic value (green roofs)
- Energy benefits (heating/cooling)
- Urban heat island reduction

POTENTIAL APPLICATIONS	
Residential	Limited
Commercial	Yes
Ultra-Urban	Yes
Industrial	Yes
Retrofit	Yes
Highway/Road	No
Recreational	Limited
Public/Private	Yes/Yes



Cross-section showing components of vegetated roof system

VARIATIONS

- Green roofs - single media system, dual media system (with synthetic liner)
- Green roofs - Intensive, Extensive, or Semi-intensive

KEY DESIGN FEATURES

- Engineered media should have a high mineral content and is typically 85% to 97% nonorganic.
- 2-6 inches of non-soil engineered media; assemblies that are 4 inches and deeper may include more than one type of engineered media.
- Irrigation is generally not required (or even desirable) for optimal stormwater management
- Internal building drainage, including provision to cover and protect deck drains or scuppers, must anticipate the need to manage large rainfall events without inundating the vegetated roof system.
- Assemblies planned for roofs with pitches steeper than 2:12 (9.5 degrees) must incorporate supplemental measures to insure stability against siding.
- The roof structure must be evaluated for compatibility with the maximum predicted dead and live loads. Typical dead loads for wet extensive vegetated covers range from about 12 to 36 pounds per square foot.
- Waterproofing must be resistant to biological and root attack. In many instances a supplemental root barrier-layer is installed to protect the primary waterproofing.
- Blue roofs: roof structure, waterproofing, accommodation for larger storm events/emergency overflows

MAINTENANCE

- Once vegetation is fully established, little maintenance needed for the extensive system
- Maintenance cost is similar to native landscaping, $0.10-$0.35 per square foot
- Blue roof maintenance is similar to conventional roof maintenance (cleaning roof and drains as necessary)

COST

- Green roofs: $10 - $35 per square foot, including all structural components, soil, and plants; more expensive than traditional roofs, but have longer lifespan; generally less expensive to install on new roof versus retrofit on existing roof
- Blue roofs: Typically add only $1-$5 per square foot compared to traditional roofs

POTENTIAL LIMITATIONS

- Green roofs have higher maintenance needs until vegetation is established
- Need for adequate roof structure and waterproofing; can be challenging on retrofit application

STORMWATER QUANTITY FUNCTIONS*		STORMWATER QUALITY FUNCTIONS*		ADDITIONAL CONSIDERATIONS	
Volume	Medium/High	TSS	Low/Medium	Capital Cost	High
Groundwater Recharge	Low	TP	Low/Medium	Maintenance	Medium
Peak Rate	Medium	TN	Low	Winter Performance	Medium
Erosion Reduction	Low/Medium	Temperature	Medium	Fast Track Potential	Low
Flood Protection	Low/Medium			Aesthetics	High

**For green roofs, blue roofs primarily function for peak rate control and flood protection.*

FACT SHEET: POROUS PAVEMENT

Porous asphalt basketball courts (Lancaster, PA)

Porous (pervious) pavement is a Green Infrastructure (GI) technique that combines stormwater infiltration, storage, and a structural pavement consisting of a permeable surface underlain by a storage/infiltration bed. Porous pavement is well suited for parking areas, walking paths, sidewalks, playgrounds, plazas, basketball courts, and other similar uses.

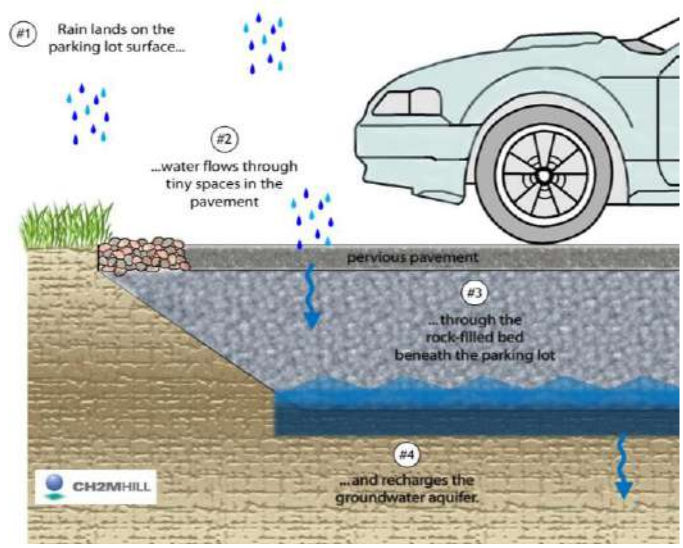
A porous pavement system consists of a pervious surface course underlain by a storage bed, typically placed on uncompacted subgrade to facilitate stormwater infiltration. The subsurface storage reservoir may consist of a stone bed of uniformly graded, clean and washed course aggregate with a void space of approximately 40% or other manufactured structural storage units. Porous pavement may be asphalt, concrete, permeable paver blocks, reinforced turf/gravel, or other emerging types of pavement.

BENEFITS

- Volume control & GW recharge, moderate peak rate control
- Versatile with broad applicability
- Dual use for pavement structure and stormwater management
- Pavers come in range of sizes and colors
- Opportunity for public education/demonstration

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra Urban	Yes
Industrial	Limited
Retrofit	Yes
Highway	Limited
Recreational	Yes
Public/Private	Yes/Yes

Porous pavers (San Diego)



Conceptual diagram showing how porous pavement functions

KEY DESIGN FEATURES

- Soil testing required for infiltration designs
- Limit amount of adjacent areas that drain directly onto the surface of the porous pavement
- Uncompacted soil subgrade for infiltration
- Level storage bed bottoms
- Provide positive storm water overflow from bed
- Surface permeability greater than 20 inches per hour
- Secondary inflow mechanism recommended
- Pretreatment for sediment-laden runoff, limit sources of sediment/debris deposition

SITE FACTORS

- Water Table/Bedrock Separation: 2-foot minimum
- Soils: HSG A&B preferred; HSG C&D may require underdrains
- Feasibility on steeper slopes: Low
- Potential Hotspots: Not without design of pretreatment system/impervious liner

MAINTENANCE

- Clean inlets
- Vacuum biannually
- Maintain adjacent landscaping/planting beds
- Periodic replacement of aggregate in paver block joints (if applicable)
- Careful winter maintenance (no sand or other abrasives, careful plowing)

COST

- Varies by porous pavement type
- Local quarry needed for stone filled infiltration bed
- Typically $7-$15 per square foot, including underground stormwater storage bed
- Generally more than standard pavement, but saves on cost of other BMPs and traditional drainage infrastructure

POTENTIAL LIMITATIONS

- Careful design & construction required
- Pervious pavement not suitable for all uses/not suitable for steep slopes
- Higher maintenance needs than standard pavement

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	High	TSS*	High	Capital Cost	Medium
Groundwater Recharge	High	TP	High	Maintenance	Medium
Peak Rate	Medium/High	TN	Medium	Winter Performance	Medium/High
Erosion Reduction	Medium/High	Temperature	High	Fast Track Potential	Low/Medium
Flood Protection	Medium/High			Aesthetics	Low to High

** While porous pavements typically result in low TSS loads, sources of sediment should be minimized to reduce the risk of clogging.*

FACT SHEET: SOIL AMENDMENTS

Healthy soils help vegetation thrive while also increasing soil infiltration rates Photo: S.Coronado

Soil amendments can include a variety of practices that reduce the generation of runoff by improving vegetation growth, increasing water infiltration, and improving water holding capacity. For example, on existing turf grass, soil amendments can include placing a thin layer of compost or other materials and spreading them evenly over existing vegetation. Amendments on existing turf grass areas can be applied for several years to improve soil over time. Soil testing can indicate how many applications are appropriate. Existing grass areas can also be aerated to improve water transmission and allow for deeper incorporation of compost.

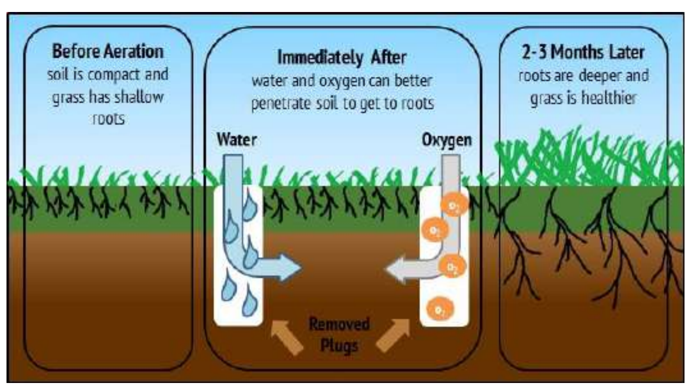
On new construction, redevelopment, and restoration projects, compost can be applied and deeply tilled into compacted soils to restore their porosity before the areas are re-vegetated (potentially with native landscaping, combining the benefits of both GI strategies).

BENEFITS

- Enhanced soil health and vegetation growth/root depth
- Improved soil infiltration rates
- Enhanced soil water holding capacity
- Reduced stormwater runoff from soil surface

POTENTIAL APPLICATIONS	
Residential	Yes
Commercial	Yes
Ultra-Urban	Limited
Industrial	Yes
Retrofit	Yes
Highway/Road	Yes
Recreational	Yes
Public/Private	Yes/Yes

A variety of soil amendments are available depending on the specific soil conditions and desired result. Photo: Pahls Market



Physical aeration (tilling) can also help improve soil health and soil permeability/porosity. Image: GreenMaxLawns

VARIATIONS

- Treating turf grass or areas with more intensive plant palettes
- Combining amended soil areas with downspout disconnection
- Physical aeration/tilling of turf grass/vegetated areas can help to remedy soil compaction
- Compost, sand, microbes, mycorrhizae, gypsum, biochar, manure, worm castings, etc.
- Amendments can improve soil aggregation, increase porosity, and improve aeration and rooting depth

KEY DESIGN FEATURES

- Soil bulk density and soil nutrient testing required
- Existing soil conditions should be evaluated before forming an amendment strategy

SITE FACTORS

- Water table to bedrock depth – N/A
- Soils – Bulk density and nutrient levels
- Slope – Not recommended for use on slopes greater than 3:1
- Potential hotspots – N/A
- Maximum drainage area – N/A

MAINTENANCE

- Replenishment of amendments on a regular basis may be required
- Aeration of soil often done at same time

COST

- The cost of soil amendments ranges widely depending on the size and type. Larger projects are estimated to cost approximately $5,000 per acre.

POTENTIAL LIMITATIONS

- Viability depends upon soil testing results
- Certain types of soil may not be favorable for success with amendments
- Not a regulated industry – testing of amendment may be needed to ensure specifications
- Physical aeration should not be done near existing tree roots

STORMWATER QUANTITY FUNCTIONS		STORMWATER QUALITY FUNCTIONS		ADDITIONAL CONSIDERATIONS	
Volume	Medium	TSS*	Medium	Capital Cost	Low
Groundwater Recharge	Medium	TP*	Medium	Maintenance	Low/Medium
Peak Rate	Medium	TN*	Medium	Winter Performance	Medium
Erosion Reduction	High	Temperature	Low	Fast Track Potential	Medium
Flood Protection	Low/Medium			Aesthetics	Medium

**Water quality benefits expected to vary widely depending on the condition of the soil/landscape prior to soil amendments.*

Appendix D
Alternatives Analysis Results

Attachment D - Alternative Analysis Summary

Tabulation of Solutions, Costs, and Scoring for Four Mile Run High-Priority Problem Areas

		Solution Summary			Flood Volume Summary					Weighted Solution Score								
Problem Area ID	Solution Technology (Conveyance, Storage, Low GI, Medium GI, High GI)	Project Name	Cost ($M)	Benefit-Cost Ratio	Existing Flood Volume (MG)	Solution Flood Volume (MG)	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)	Urban Drainage/ Flooding	Environmental Compliance	EcoCity Goals/ Sustainability	Social Benefits	Integrated Asset Management	City-Wide Maintenance Implications	Constructability	Public Acceptance	Total
101	Low GI	LGI-101	$ 1.106	38.1	3.54	1.38	2.16	61%	$ 0.51	10.5	2.6	3.9	3.1	0.0	13.0	4.3	4.8	42.1
101	Storage	STOR-101	$ 3.791	7.0	3.54	0.13	3.41	96%	$ 1.11	16.5	0.0	0.0	0.0	0.0	3.2	2.2	4.8	26.7
101	Medium GI	MGI-101	$ 5.524	8.8	3.54	1.18	2.36	67%	$ 2.34	11.4	7.9	3.9	3.1	0.0	13.0	4.3	4.8	48.4
101	Conveyance	CONV-101	$ 3.909	7.6	3.54	2.10	1.44	41%	$ 2.70	6.6	0.0	0.0	0.0	0.0	16.2	2.2	4.8	29.8
101	High GI	HGI-101	$ 14.087	3.9	3.54	0.97	2.57	73%	$ 5.48	12.4	13.3	3.9	3.1	0.0	13.0	4.3	4.8	54.9
102	Low GI	LGI-102	$ 0.380	88.1	2.17	1.82	0.35	16%	$ 1.09	2.8	2.7	3.3	2.6	0.0	13.0	4.3	4.8	33.5
102	Storage	STOR-102	$ 2.357	11.0	2.17	0.46	1.71	79%	$ 1.38	13.5	0.0	0.0	0.0	0.0	3.2	4.3	4.8	25.9
102	Medium GI	MGI-102	$ 1.896	21.9	2.17	1.51	0.66	31%	$ 2.87	5.2	8.2	3.3	2.6	0.0	13.0	4.3	4.8	41.5
102	High GI	HGI-102	$ 4.836	10.1	2.17	1.32	0.85	39%	$ 5.68	6.7	13.9	3.3	2.6	0.0	13.0	4.3	4.8	48.6
102	Conveyance	CONV-102	$ 2.605	80.1	2.17	1.77	0.40	18%	$ 6.54	185.5	0.0	0.0	0.0	0.0	16.2	2.2	4.8	208.7
103	Low GI	LGI-103	$ 0.289	136.6	0.35	0.33	0.02	6%	$ 14.14	1.0	2.5	4.0	3.2	6.6	13.0	4.3	4.8	39.4
103	Conveyance	CONV-103	$ 0.925	39.3	0.35	0.03	0.32	93%	$ 2.88	0.0	0.0	0.0	0.0	13.2	16.2	2.2	4.8	36.4
103	Medium GI	MGI-103	$ 1.441	32.5	0.35	0.29	0.06	17%	$ 23.76	3.0	7.9	4.0	3.2	6.6	13.0	4.3	4.8	46.8
103	Storage	STOR-103	$ 0.874	27.8	0.35	0.06	0.29	82%	$ 3.07	14.1	0.0	0.0	0.0	0.0	3.2	2.2	4.8	24.3
103	High GI	HGI-103	$ 3.674	14.9	0.35	0.24	0.11	31%	$ 33.72	5.4	13.4	4.0	3.2	6.6	13.0	4.3	4.8	54.6
104	Low GI	LGI-104	$ 0.177	218.8	0.45	0.42	0.02	6%	$ 7.19	0.9	2.6	3.7	3.0	0.0	13.0	10.8	4.8	38.8
104	Conveyance	CONV-104	$ 0.588	43.2	0.45	0.05	0.40	88%	$ 1.48	0.0	0.0	0.0	0.0	0.0	16.2	4.3	4.8	25.4
104	Medium GI	MGI-104	$ 0.886	51.6	0.45	0.38	0.07	16%	$ 12.19	2.8	7.6	3.7	3.0	0.0	13.0	10.8	4.8	45.7
104	Storage	STOR-104	$ 1.891	8.3	0.45	0.30	0.14	32%	$ 13.15	5.5	0.0	0.0	0.0	0.0	3.2	2.2	4.8	15.7
104	High GI	HGI-104	$ 2.259	23.3	0.45	0.33	0.12	27%	$ 18.62	4.6	12.6	3.7	3.0	0.0	13.0	10.8	4.8	52.6
105	Low GI	LGI-105	$ 0.126	260.4	0.65	0.60	0.05	8%	$ 2.38	1.4	2.7	3.6	2.9	0.0	13.0	4.3	4.8	32.7
105	Conveyance	CONV-105	$ 0.868	37.1	0.65	0.12	0.53	82%	$ 1.63	9.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	32.2
105	Medium GI	MGI-105	$ 0.627	65.2	0.65	0.49	0.17	26%	$ 3.74	4.4	7.9	3.6	2.9	0.0	13.0	4.3	4.8	40.9
105	High GI	HGI-105	$ 1.599	30.9	0.65	0.36	0.29	44%	$ 5.52	7.6	13.2	3.6	2.9	0.0	13.0	4.3	4.8	49.4
106	Low GI	LGI-106	$ 0.077	571.6	0.13	0.08	0.05	36%	$ 1.65	6.2	2.3	3.8	3.1	0.0	13.0	10.8	4.8	44.0
106	Medium GI	MGI-106	$ 0.384	138.9	0.13	0.05	0.08	63%	$ 4.70	10.8	7.1	3.8	3.1	0.0	13.0	10.8	4.8	53.4
106	High GI	HGI-106	$ 0.980	63.1	0.13	0.02	0.11	85%	$ 8.91	14.5	11.9	3.8	3.1	0.0	13.0	10.8	4.8	61.9
106	Conveyance	CONV-106	$ 0.369	93.1	0.13	-	0.13	100%	$ 2.84	11.2	0.0	0.0	0.0	0.0	16.2	2.2	4.8	34.3
107	Low GI	LGI-107	$ 0.484	81.3	3.65	3.50	0.16	4%	$ 3.07	0.7	2.2	4.3	3.4	6.6	13.0	4.3	4.8	39.4
107	Conveyance	CONV-107	$ 0.803	37.1	3.65	4.37	N/A	-19%	N/A	0.0	0.0	0.0	0.0	6.6	16.2	2.2	4.8	29.8
107	Medium GI	MGI-107	$ 2.418	18.4	3.65	3.38	0.27	8%	$ 8.81	1.3	6.6	4.3	3.4	6.6	13.0	4.3	4.8	44.4
107	Storage	STOR-107	$ 2.661	10.0	3.65	1.58	2.07	57%	$ 1.28	9.7	0.0	0.0	0.0	6.6	3.2	2.2	4.8	26.5
107	High GI	HGI-107	$ 6.167	8.2	3.65	3.06	0.60	16%	$ 10.35	2.8	11.1	4.3	3.4	6.6	13.0	4.3	4.8	50.4
108	Low GI	LGI-108	$ 0.004	12088.6	0.01	0.01	0.00	30%	$ 1.23	5.1	2.3	3.6	2.9	0.0	13.0	10.8	4.8	42.5
108	High GI	HGI-108	$ 0.045	1368.5	0.01	0.00	0.01	85%	$ 5.46	14.7	11.5	3.6	2.9	0.0	13.0	10.8	4.8	61.3
108	Medium GI	MGI-108	$ 0.018	2920.2	0.01	0.00	0.01	54%	$ 3.39	9.3	6.9	3.6	2.9	0.0	13.0	10.8	4.8	51.3
108	Conveyance	CONV-108	$ 0.176	144.5	0.01	-	0.01	100%	$ 18.30	0.0	0.0	0.0	0.0	0.0	16.2	4.3	4.8	25.4
109	Low GI	LGI-109	$ 0.287	144.7	0.29	0.23	0.05	19%	$ 5.34	3.2	2.0	4.3	3.4	6.6	13.0	4.3	4.8	41.5
109	Storage	STOR-109	$ 0.767	44.2	0.29	-	0.29	100%	$ 2.66	17.1	0.0	0.0	0.0	6.6	3.2	2.2	4.8	33.9
109	Medium GI	MGI-109	$ 1.433	31.7	0.29	0.23	0.05	19%	$ 26.80	3.2	5.9	4.3	3.4	6.6	13.0	4.3	4.8	45.5
109	Conveyance	CONV-109	$ 1.009	31.5	0.29	0.25	0.03	12%	$ 29.69	2.0	0.0	0.0	0.0	6.6	16.2	2.2	4.8	31.8
109	High GI	HGI-109	$ 3.653	15.1	0.29	0.14	0.15	52%	$ 24.42	8.9	9.9	4.3	3.4	6.6	13.0	4.3	4.8	55.2
110	Low GI	LGI-110	$ 0.140	224.1	1.28	1.22	0.06	5%	$ 2.25	0.8	2.0	3.6	2.9	0.0	13.0	4.3	4.8	31.4
110	Storage	STOR-110	$ 0.242	57.7	1.28	1.16	0.12	9%	$ 2.03	1.6	0.0	0.0	0.0	0.0	3.2	4.3	4.8	14.0
110	Medium GI	MGI-110	$ 0.700	52.9	1.28	1.10	0.19	15%	$ 3.74	2.5	5.9	3.6	2.9	0.0	13.0	4.3	4.8	37.0
110	Conveyance	CONV-110	$ 1.375	26.4	1.28	-	1.28	100%	$ 1.07	13.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	36.2
110	High GI	HGI-110	$ 1.784	24.0	1.28	0.96	0.33	25%	$ 5.48	4.3	9.8	3.6	2.9	0.0	13.0	4.3	4.8	42.8
111	Low GI	LGI-111	$ 0.080	422.0	0.28	0.23	0.05	17%	$ 1.72	2.9	2.3	3.6	2.9	0.0	13.0	4.3	4.8	33.8
111	Storage	STOR-111	$ 0.068	206.6	0.28	0.25	0.03	9%	$ 2.56	1.6	0.0	0.0	0.0	0.0	3.2	4.3	4.8	14.0
111	Conveyance	CONV-111	$ 0.627	64.3	0.28	-	0.28	100%	$ 2.25	17.1	0.0	0.0	0.0	0.0	16.2	2.2	4.8	40.3
111	Medium GI	MGI-111	$ 0.400	109.1	0.28	0.15	0.13	46%	$ 3.08	8.0	7.1	3.6	2.9	0.0	13.0	4.3	4.8	43.6
111	High GI	HGI-111	$ 1.020	51.4	0.28	0.08	0.20	70%	$ 5.22	12.0	11.8	3.6	2.9	0.0	13.0	4.3	4.8	52.4
112	Low GI	LGI-112	$ 0.080	478.3	0.19	0.18	0.01	7%	$ 6.20	1.1	2.0	3.6	2.9	0.0	13.0	10.8	4.8	38.2
112	Medium GI	MGI-112	$ 0.399	111.6	0.19	0.15	0.04	20%	$ 10.11	3.5	5.9	3.6	2.9	0.0	13.0	10.8	4.8	44.6
112	Conveyance	CONV-112	$ 0.506	45.8	0.19	-	0.19	100%	$ 2.62	0.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	23.2
112	High GI	HGI-112	$ 1.018	50.0	0.19	0.13	0.07	34%	$ 15.31	5.9	9.9	3.6	2.9	0.0	13.0	10.8	4.8	50.9
113	Low GI	LGI-113	$ 0.147	271.2	0.13	0.11	0.02	15%	$ 7.63	2.5	2.1	3.6	2.9	0.0	13.0	10.8	4.8	39.8

		Solution Summary			Flood Volume Summary					Weighted Solution Score								
Problem Area ID	Solution Technology (Conveyance, Storage, Low GI, Medium GI, High GI)	Project Name	Cost ($M)	Benefit-Cost Ratio	Existing Flood Volume (MG)	Solution Flood Volume (MG)	Flood Volume Reduction (MG)	Flood Volume Reduction (%)	Cost/Gallon of Flood Reduction ($/gal)	Urban Drainage/ Flooding	Environmental Compliance	EcoCity Goals/ Sustainability	Social Benefits	Integrated Asset Management	City-Wide Maintenance Implications	Constructability	Public Acceptance	Total
113	Storage	STOR-113	$ 0.369	80.0	0.13	-	0.13	100%	$ 2.86	17.1	0.0	0.0	0.0	0.0	3.2	4.3	4.8	29.5
113	Medium GI	MGI-113	$ 0.732	66.3	0.13	0.08	0.05	41%	$ 13.67	7.1	6.3	3.6	2.9	0.0	13.0	10.8	4.8	48.5
113	Conveyance	CONV-113	$ 0.231	155.1	0.13	-	0.13	100%	$ 1.79	10.4	0.0	0.0	0.0	0.0	16.2	4.3	4.8	35.8
113	High GI	HGI-113	$ 1.867	30.7	0.13	0.04	0.09	67%	$ 21.45	11.5	10.6	3.6	2.9	0.0	13.0	10.8	4.8	57.2
114	Low GI	LGI-114	$ 0.088	463.5	0.32	0.28	0.04	11%	$ 2.48	1.9	2.4	4.4	3.5	6.6	13.0	4.3	4.8	41.0
114	High GI	HGI-114	$ 1.125	55.5	0.32	0.12	0.20	63%	$ 5.70	10.7	15.0	4.4	3.5	6.6	13.0	4.3	4.8	62.4
114	Medium GI	MGI-114	$ 0.441	117.1	0.32	0.20	0.12	37%	$ 3.75	6.4	8.6	4.4	3.5	6.6	13.0	4.3	4.8	51.7
114	Conveyance	CONV-114	$ 0.761	47.8	0.32	0.00	0.32	100%	$ 2.41	0.0	0.0	0.0	0.0	13.2	16.2	2.2	4.8	36.4
114	Storage	STOR-114	$ 0.301	78.3	0.32	0.11	0.21	65%	$ 1.46	11.2	0.0	0.0	0.0	0.0	3.2	4.3	4.8	23.6
115	Low GI	LGI-115	$ 0.093	388.0	0.34	0.32	0.02	5%	$ 5.31	0.9	3.1	1.9	1.5	0.0	13.0	10.8	4.8	36.0
115	High GI	HGI-115	$ 1.181	47.3	0.34	0.19	0.16	45%	$ 7.59	7.8	16.0	1.9	1.5	0.0	13.0	10.8	4.8	55.9
115	Medium GI	MGI-115	$ 0.463	97.8	0.34	0.27	0.08	22%	$ 6.12	3.8	9.4	1.9	1.5	0.0	13.0	10.8	4.8	45.3
115	Conveyance	CONV-115	$ 0.249	101.7	0.34	-	0.34	100%	$ 0.73	0.0	0.0	0.0	0.0	0.0	16.2	4.3	4.8	25.4
116	Low GI	LGI-116	$ 0.438	90.7	1.16	1.06	0.10	9%	$ 4.43	1.5	2.5	4.0	3.2	0.0	13.0	10.8	4.8	39.7
116	Medium GI	MGI-116	$ 2.186	21.4	1.16	0.94	0.22	19%	$ 9.75	3.3	7.7	4.0	3.2	0.0	13.0	10.8	4.8	46.8
116	Conveyance	CONV-116	$ 1.566	14.8	1.16	1.32	N/A	-13%	N/A	0.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	23.2
116	High GI	HGI-116	$ 5.573	9.7	1.16	0.80	0.37	31%	$ 15.26	5.4	13.1	4.0	3.2	0.0	13.0	10.8	4.8	54.2
117	Low GI	LGI-117	$ 0.048	903.3	1.34	1.26	0.07	6%	$ 0.65	1.0	2.8	6.2	4.9	0.0	13.0	10.8	4.8	43.4
117	Medium GI	MGI-117	$ 0.240	212.9	1.34	1.11	0.23	17%	$ 1.05	2.9	8.5	6.2	4.9	0.0	13.0	10.8	4.8	51.1
117	Conveyance	CONV-117	$ 0.303	86.4	1.34	1.28	0.06	4%	$ 5.05	0.8	0.0	0.0	0.0	0.0	16.2	4.3	4.8	26.1
117	High GI	HGI-117	$ 0.612	96.1	1.34	0.96	0.37	28%	$ 1.65	4.8	14.3	6.2	4.9	0.0	13.0	10.8	4.8	58.8
117	Storage	STOR-117	$ 0.784	30.8	1.34	0.25	1.08	81%	$ 0.72	13.9	0.0	0.0	0.0	0.0	3.2	2.2	4.8	24.1
118	Low GI	LGI-118	$ 0.039	1052.0	0.42	0.38	0.04	9%	$ 1.05	1.5	2.6	3.6	4.3	0.0	13.0	10.8	4.8	40.7
118	Medium GI	MGI-118	$ 0.193	253.5	0.42	0.31	0.11	26%	$ 1.80	4.4	8.0	3.6	4.3	0.0	13.0	10.8	4.8	49.0
118	Storage	STOR-118	$ 0.149	117.9	0.42	0.36	0.06	14%	$ 2.62	2.3	0.0	0.0	2.9	0.0	3.2	4.3	4.8	17.6
118	High GI	HGI-118	$ 0.493	116.5	0.42	0.24	0.18	43%	$ 2.74	7.4	13.5	3.6	4.3	0.0	13.0	10.8	4.8	57.4
118	Conveyance	CONV-118	$ 0.360	98.7	0.42	0.10	0.32	76%	$ 1.13	9.5	0.0	0.0	2.9	0.0	16.2	2.2	4.8	35.5
119	Low GI	LGI-119	$ 0.114	278.0	0.24	0.20	0.04	17%	$ 2.82	2.8	0.0	3.7	2.9	0.0	13.0	4.3	4.8	31.5
119	High GI	HGI-119	$ 1.445	40.8	0.24	0.04	0.21	85%	$ 7.00	14.6	15.7	3.7	2.9	0.0	13.0	4.3	4.8	59.0
119	Medium GI	MGI-119	$ 0.567	81.6	0.24	0.13	0.12	48%	$ 4.85	8.3	9.3	3.7	2.9	0.0	13.0	4.3	4.8	46.3
119	Storage	STOR-119	$ 0.890	28.7	0.24	0.03	0.22	89%	$ 4.10	15.3	0.0	0.0	0.0	0.0	3.2	2.2	4.8	25.5
119	Conveyance	CONV-119	$ 0.537	43.2	0.24	0.15	0.09	38%	$ 5.77	0.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	23.2
120	Medium GI	MGI-120	$ 0.696	77.2	0.01	-	0.01	100%	$ 138.58	17.1	8.5	3.4	2.7	0.0	13.0	4.3	4.8	53.8
120	Low GI	LGI-120	$ 0.139	310.7	0.01	0.00	0.00	88%	$ 31.36	15.2	0.0	3.4	2.7	0.0	13.0	4.3	4.8	43.3
120	High GI	HGI-120	$ 1.776	33.6	0.01	-	0.01	100%	$ 353.38	17.1	14.4	3.4	2.7	0.0	13.0	4.3	4.8	59.7
120	Storage	STOR-120	$ 1.077	25.4	0.01	-	0.01	100%	$ 214.23	17.1	0.0	0.0	0.0	0.0	3.2	2.2	4.8	27.3
120	Conveyance	CONV-120	$ 0.275	84.5	0.01	-	0.01	100%	$ 54.63	0.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	23.2
121	Low GI	LGI-121	$ 0.041	752.2	0.07	0.06	0.01	14%	$ 4.37	2.3	0.0	3.7	3.0	0.0	13.0	4.3	4.8	31.1
121	Storage	STOR-121	$ 0.448	61.6	0.07	0.01	0.06	89%	$ 7.21	15.3	0.0	0.0	0.0	0.0	3.2	4.3	4.8	27.6
121	Conveyance	CONV-121	$ 0.415	61.2	0.07	0.06	0.01	21%	$ 28.36	0.0	0.0	0.0	0.0	0.0	16.2	4.3	4.8	25.4
121	Medium GI	MGI-121	$ 0.207	208.8	0.07	0.04	0.03	40%	$ 7.47	6.8	7.6	3.7	3.0	0.0	13.0	4.3	4.8	43.2
121	High GI	HGI-121	$ 0.527	98.8	0.07	0.03	0.04	62%	$ 12.19	10.6	12.7	3.7	3.0	0.0	13.0	4.3	4.8	52.1
122	Low GI	LGI-122	$ 0.022	1669.2	0.14	0.13	0.01	8%	$ 1.83	1.4	0.0	3.6	2.9	0.0	13.0	10.8	4.8	36.6
122	Conveyance	CONV-122	$ 0.581	68.7	0.14	-	0.14	100%	$ 4.08	16.7	0.0	0.0	0.0	0.0	16.2	2.2	4.8	39.9
122	Medium GI	MGI-122	$ 0.109	422.4	0.14	0.11	0.04	26%	$ 2.98	4.4	6.7	3.6	2.9	0.0	13.0	10.8	4.8	46.2
122	Storage	STOR-122	$ 0.233	107.4	0.14	0.02	0.12	86%	$ 1.89	14.8	0.0	0.0	0.0	0.0	3.2	2.2	4.8	25.0
122	High GI	HGI-122	$ 0.279	192.4	0.14	0.08	0.06	43%	$ 4.55	7.4	11.2	3.6	2.9	0.0	13.0	10.8	4.8	53.7
123	Conveyance	CONV-123	$ 0.219	183.3	0.10	-	0.10	100%	$ 2.21	17.0	0.0	0.0	0.0	0.0	16.2	2.2	4.8	40.2
123	Low GI	LGI-123	$ 0.112	249.3	0.10	0.07	0.03	27%	$ 4.21	4.6	0.0	0.7	0.5	0.0	13.0	4.3	4.8	28.0
123	Storage	STOR-123	$ 0.406	67.3	0.10	-	0.10	100%	$ 4.10	17.1	0.0	0.0	0.0	0.0	3.2	2.2	4.8	27.3
123	High GI	HGI-123	$ 1.428	39.6	0.10	-	0.10	100%	$ 14.42	17.1	16.1	0.7	0.5	0.0	13.0	4.3	4.8	56.6
123	Medium GI	MGI-123	$ 0.560	81.6	0.10	0.03	0.07	74%	$ 7.59	12.8	9.6	0.7	0.5	0.0	13.0	4.3	4.8	45.7

Appendix E
Basis of Cost

City of Alexandria Storm Sewer Capacity Analysis

Planning Level Cost Information

PREPARED FOR:	City of Alexandria Transportation and Engineering Services
COPY TO:	File
PREPARED BY:	CH2M HILL
DATE:	May 15, 2014
PROJECT NUMBER:	240027

Introduction

The City of Alexandria, Virginia, has experienced repeated and increasingly frequent flooding events attributable to old infrastructure, inconsistent design criteria, and perhaps climate change. The purpose of the stormwater capacity analysis project is to provide a program for analyzing storm sewer capacity issues, identifying problem areas, developing and prioritizing solutions, and providing support for public outreach and education. The project is being implemented in phases by watershed. The watersheds include Hooffs Run, Four Mile Run, Holmes Run, Cameron Run, Taylor Run, Strawberry Run, Potomac River, and Backlick Run.

This technical memorandum provides details on the basis of cost estimates developed for each solution and the watershed wide alternatives. The information includes panning level unit cost for conveyance, storage and green infrastructure solutions.

These cost estimates are considered a Class 4 - Planning Level estimate as defined by the American Association of Cost Engineering (AACE), International Recommended Practice No. 18R-97, and as designated in ASTM E 2516-06. It is considered accurate to +50% to -30% based up to a 15% complete project definition.

Definitions

The following cost terminologies are used within this technical memorandum:

- Construction cost: Installed cost, including materials, labor, and site adjustment factors such as overcoming utility conflicts, dewatering, and pavement restoration.
- ENRCCI Cost Adjustment Factor: Cost adjustment factor of 0.9 to adjust cost to October 2013 dollars for the DC-Baltimore metro area
- Service and Contingency Factor (SCF): A factor of 1.4 is applied for this project to account for engineering and design expenses (20%) and for contingency allowance (20%).
- Capital cost: Construction cost multiplied by a Service and Contingency Factor (SCF) to cover engineering and design and contingency allowance.
- Operating cost: Operation and maintenance were not considered for this project.

Gravity Sewer Relief Costs

Conveyance projects were costed on a per linear foot basis, based on pipe size and depth. The construction cost rates ($/ft) for gravity sewer replacement are listed in Table 1. Cost rates are shown for different road types. The Gravity sewer cost rates include complete installation of sewer pipes, inlets/manholes, and other ancillary structures as well as surface restoration. The costs were established through literature review and updated based on an assessment of bid tabulation data from Kansas City metro area between 2008 and 2012, and a comparison to Fairfax County, VA unit cost schedule, March 2013. All costs were adjusted to Washington DC, 2013 dollars using Engineering News-Record Construction Cost Index (ENRCCI) adjustment factors.

Factors are applied to the construction cost of gravity sewer pipe replacement to reflect the cost associated with crossing under streams and railroads as listed in Table 2.

Costs of routine O&M, inspection and cleaning at periodic intervals during the life of the gravity sewer were assumed to part of City-wide facilities maintenance plan and should take place even though those costs are not specifically included here.

TABLE 1
Open Cut Gravity Sewer Construction Costs

		Sewer Construction Cost ($/LF) (1)					
		Trench depth up to 10 feet		Trench depth 10 to 15 feet		Trench depth 15 to 20 feet	
Pipe Diameter (in)	Material	Residential	Arterial	Residential	Arterial	Residential	Arterial
8	PVC	$90	$104	$113	$130	$140	$162
10	PVC	$113	$131	$140	$163	$176	$204
12	PVC	$122	$140	$152	$175	$190	$218
15	PVC	$131	$153	$163	$192	$204	$239
18	PVC	$140	$162	$175	$203	$218	$253
21	PVC	$162	$189	$203	$237	$253	$295
24	PVC	$185	$212	$230	$265	$288	$330
30	RCP	$257	$297	$320	$372	$401	$464
36	RCP	$306	$356	$383	$445	$478	$555
42	RCP	$360	$414	$450	$518	$563	$647
48	RCP	$410	$473	$512	$590	$640	$738
54	RCP	$459	$531	$574	$664	$717	$830
60	RCP	$509	$585	$635	$732	$795	$914
72	RCP	$815	$936	$1,018	$1,170	$1,273	$1,463

(1) Listed construction costs have been adjusted to October 2013 dollars using ENRCCI for the DC-Baltimore Metro area.

TABLE 2
Gravity Pipe Construction Cost Factors

Type of Crossing	Cost Factor
Stream	3
Railroad	7

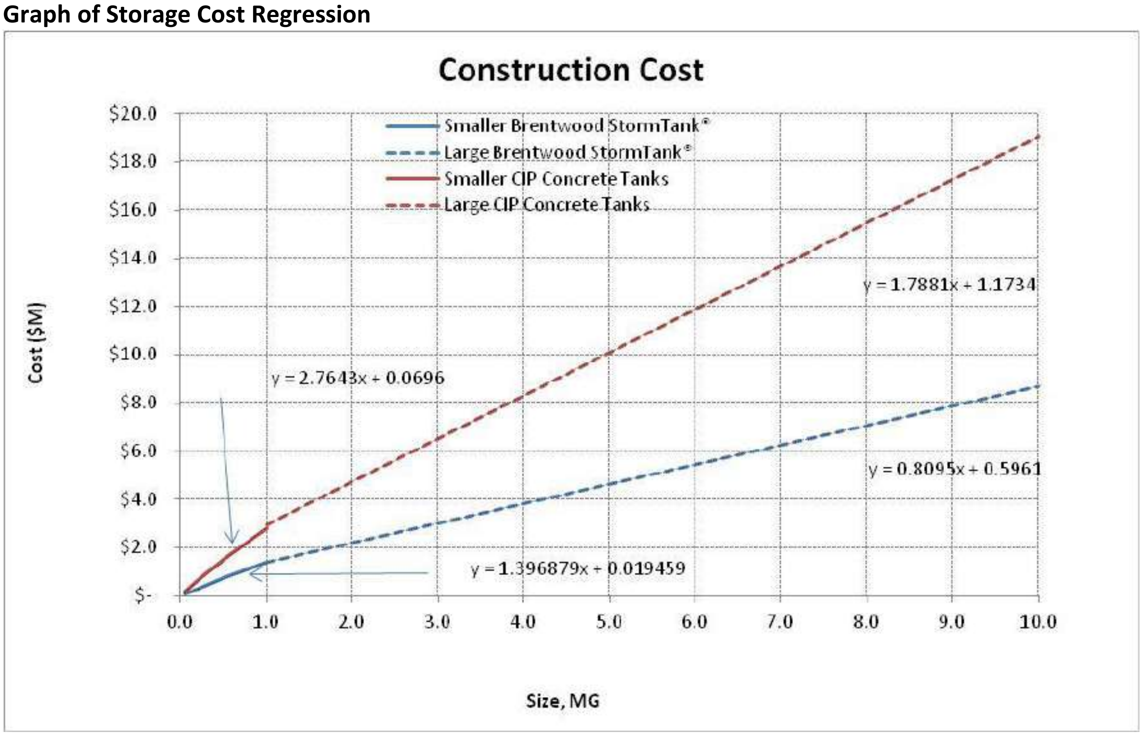
Storage Facility Cost Information

Cost estimates for the storage facilities were developed for two technologies: A traditional underground cast-in-place concrete tank and an alternative stackable modular unit installed underground and wrapped with an impermeable or permeable liner.

The CIP Concrete storage facility construction cost was developed as a customized cost estimate based on CH2M HILL's Program Alternative Cost Calculator (PACC) Tool. The costs are construction costs only and do not include administration costs, engineering costs, contingencies, and other soft costs. The costs for smaller storage units with volumes less than 1 million gallon were found to be high for the CIP concrete tank. Hence, a separate takeoff cost estimate was developed for smaller storage volume; less than 1 million gallons.

A separate cost estimate was developed for the stackable modular units. There is an increasing use of these technologies in the industry and the cost of installation is getting increasingly competitive compared to traditional storage methods. Construction costs were developed based on one such stackable modular unit, StormTank® modules by Brentwood Industries. The cost for the Brentwood StormTank® modules came out significantly less than that for CIP concrete tanks. For the purpose of the evaluation of watershed wide alternative solutions, the StormTank® modules was used as the most cost effective alternative, however site specific conditions will determine which technology will be most appropriate in a given location. For example a site with high water table may make the use of CIP concrete tanks preferable over the StormTank® modules. The estimated construction costs for the CIP concrete tanks and the Brentwood StormTank® are provided in Figure 1.

FIGURE 1
Graph of Storage Cost Regression



The following assumptions were made for storage tank selection and sizing:

1. Offline enclosed underground storage will be active only during wet weather events.
2. Options for odor control were not considered.
3. Costs for storage facilities with intermediate storage volumes were interpolated based on linear regression shown in Figure 1.

Green Infrastructure (GI) Cost Information

A variety of sources and professional judgment were used to develop the GI costs. Where technologies were directly comparable, costs were updated based on Fairfax County, VA unit cost schedule, March 2013. The unit costs used to develop GI implementation cost are included in Table 4. Costs reflecting stand-alone projects (e.g., installing a green roof on top of an existing building) were used for costing alternatives solutions. Incremental costs of adding GI to an existing project can provide significant savings and are provided for reference, but not used directly in cost estimates for this project.

In the CASSCA Project GI is being proposed as a series of GI programs applicable to specific land uses (e.g. green parking is applicable to parking lots). Each GI program may consist of multiple GI technologies which drive the cost of implementing that program. Table 5 lists and the relative amounts of area designated for the GI technologies assumed to be part of each GI program and the resultant unit cost for each GI program.

TABLE 4
Unit Construction Costs of Green Infrastructure Technologies

Green Technology	Stand Alone Cost Proposed for GI Plan ($/GI acre)	Loading Ratio (Ratio of Area Managed to Area of GI)	Stand-Alone Cost Proposed for GI Plan ($/acre managed)	Incremental GI Cost Compared to Stand-Alone
Native Landscaping/Soil Amend.	$ 5,000	1	$ 5,000	50%
Rain Barrels[1] and Native Landscaping/Soil Amend.	$ -	N/A	$ 15,000	90%
Cisterns[2]	N/A	N/A	$ 34,000	90%
Blue Street/Inlet control devices	N/A	N/A	$ 22,500	N/A
Rain Gardens	$ 436,000	12	$ 36,000	70%
Stormwater Trees[3]	$ 34,700	0.5	$ 69,000	50%
Bioswale/Bioretention	$ 1,045,000	12	$ 87,000	70%
Porous Pavement/ Infiltration Trench	$ 436,000	4	$ 109,000	70%
Green Roof[4]	$ 501,000	1	$ 501,000	43%

[1] Each rain barrel is assumed to manage 350 ft^2 of rooftop; therefore, 124.5 barrels are required for 1 acre of roof.
[2] Each 1000-gallon cistern is assumed to manage 6,500 ft^2 of impervious area; therefore, 6.7 barrels are required for 1 acre.
[3] Trees are assumed to have an average 10-foot canopy radius (314 ft^2), with 50 percent assumed to be overhanging impervious area.
[4] Incremental cost of green roofs set to 43 percent to match the District's $5/ ft^2 ($217,800/acre) green roof incentive program.

TABLE 5
Green Infrastructure Technology Elements and Unit Construction Cost of Each Green Program

Green Technology	**% Area of Program Assigned to Each GI Technology**						
	Blue Streets	**Green Alley**	**Green Buildings**	**Green Parking**	**Green Roofs**	**Green Schools**	**Green Schools**
Native Landscaping/Soil Amend.	-	-		-	-	-	-
Rain Barrels[1] and Native Landscaping/Soil Amend.	-	-	30%	-	-	-	-
Cisterns	-	-	10%	-	-	-	-
Blue Street/Inlet control devices	100%					-	-
Rain Gardens	-	-	30%	-	-	-	-
Stormwater Trees	-	-		-	-	-	30%
Bioswale/Bioretention	-	-	30%	50%	-	65%	30%
Porous Pavement/ Infiltration Trench	-	100%		50%	-	30%	40%
Green Roof	-	-	-	-	100%	5%	-
Unit Cost ($/acre managed)	**$22,500**	**$109,000**	**$44,800**	**$98,000**	**$501,000**	**$114,300**	**$90,400**

Three levels of green infrastructure implementation were evaluated for this project:

- High Implementation – Manage 50% of total impervious area in the shed
- Medium Implementation – Manage 30% of total impervious area in the shed
- Low Implementation – Manage 10% of total impervious area in the shed

The unit cost of implementing GI at the various implementation levels is driven by the availability of GI opportunity areas. As the area available to achieve a GI implementation level become scarce, the cost to achieve that level on GI implementation also increases. It was assumed that GI implementation would focus, in succession, from the most to the least cost effective programs and technologies. That is, for each level of GI implementation the most cost effective program and technologies would be implemented first until the available opportunities for those programs are exhausted. If the level of implementation is not achieved with the most cost effective program, the next most cost effective program is considered in that order until the desired level of GI implementation is achieved. Therefore Low Implementation would be more cost effective (lower cost per acre managed). The unit cost for each implementation level was computed separately for each watershed based on the cost information presented above and the distribution of areas available for GI implementation.

Green Opportunities

Opportunities for blue streets, green streets and alleys, green buildings, green parking, green roofs, and green schools were identified by completing a desktop analysis using the City's 2011 basemap data, including:

- Roads (Road_y and Road_lc)
- Buildings (Blds_y)
- Parking lots (Parking_y)
- Zoning (Zoning_y)
- Parcels (Parcels_y)

The approach to identifying potential opportunities for each program is provided below. All opportunities were combined into a single shapefile of polygons with an attribute for area calculated in acres.

Blue Streets

Local or Residential roads with an average slope less than or equal to 1% and a maximum slope less than or equal to 3%. Road slope was estimated using ArcGIS 3D Analyst tools and the Road_lc feature and City of Alexandria DEM as inputs.

Green Streets and Alleys

Green streets and alleys were identified using the Road_lc and Road_y features to identify roads classed as Arterial, Primary Collector, Residential Collector, Local, and Alley with an average slope less than or equal to 5%. Roadways that fall within school parcels were removed from this layer because they are included in the Green Schools program. Road slope was estimated using ArcGIS 3D analyst tools and the Road_lc feature and City of Alexandria DEM as inputs.

Green Buildings

Green buildings opportunities include buildings where disconnection may be possible. Based on a windshield survey of Taylor Run, approximately 50% of residential buildings, not including single family detached homes, may have opportunities for downspout disconnection. To identify these opportunities, buildings with a BUSE of '1-Residential' were selected from the Blds_y features to identify all residential buildings. This selection was narrowed to apartment buildings and larger residential developments, removing detached houses (BTYPE = 'Detached house'), buildings with less than 5 units (BUNITS < 5), as well as removing nursing homes, hotels, and detention centers. Residential buildings on school properties were also removed because those are accounted for in the Green Schools program. Buildings with a footprint greater than 20,000 square feet were also removed because these buildings are likely too large for a disconnection program.

The footprint of the final selection was reduced by approximately 50% (based on the result of the Taylor Run windshield survey) to approximate the total area of impervious surfaces that could potentially be managed through a disconnection program.

Green Parking

Green parking opportunities were identified as parking lots in the Parking_y feature class with a parking area over 3,000 square feet. Parking lots on school parcels were removed from this selection because they are accounted for in the Green Schools program.

Green Roofs

Green roof opportunities were identified by selecting buildings in the Blds_y feature class with a footprint over 20,000 ft^2 that have a building use (BUSE) of Commercial, Industrial, Institution, Transportation, and Multiple or Mixed use. Also included were buildings over 20,0000 ft^2 that were within a Commercial, Industrial, Coordinated Development District, or Mixed Use zone based on the Zoning_y feature class, unless those buildings were garage/sheds. Buildings on school parcels were removed from this selection because they are accounted for in the Green Schools program.

Green Schools

School parcels were identified by selecting all parcels with a land description (LANDDESC) of 'ED. PUBLIC SCHOOLS', 'PRIVATE ED ENSTS.', or 'ST. ED. INSTITUTIONS' or with an owner name or address that indicated it was school property. School buildings with potential for green roofs were identified by selecting all buildings on school parcels or buildings in the Blds_y features with the word 'school' in the building name (BNAME) or building campus (BCAMPUS) fields where the footprint is over 3,000 ft^2. All remaining impervious surfaces on the school parcels (roads, sidewalks, small buildings, recreation facilities, etc.) were identified as opportunities for green schools.